WIRELESS

A58V TELEVISION & RADIO RECEIVER

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Frontispiece

WIRELESS

An account of the
General Principles underlying
the modern magic of Wireless Reception

by

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PREFACE

THE general principles of wireless reception do not change much to-day, but the practical details do, so in one sense a book on wireless is never out-of-date, and in another sense it is outmoded as soon as written. Therefore I have in this work treated mainly of fundamental principles, and if any reader becomes an enthusiast he can read the appropriate periodicals and keep up-to-date.

An assumption is made that the reader knows the most elementary arithmetic and mathematics, such as the decimal system (now taught in all elementary schools) and algebra up to simple equations. Wherever any other branch of mathematics is introduced, it is explained.

C.L.B.

CONTENTS

LIST OF PLATES

CHAPTER I

WAVES

WE all glibly talk to-day of wireless waves. So familiar are we with the words that we no longer think about them. Yet they deserve examination if we are to understand the problems of wireless reception.

What then is a wave? Let us first consider a very simple illustration. Imagine a cork on perfectly placid water. It is quite still. A stone is thrown into that water and immediately ripples appear to spread out from the place of impact. They travel away from the centre. But if we watch the cork we see that it bobs up and down but *does not move away from the centre of the circle of ripples.* When these have at last ceased the cork is once more still and in the position it originally occupied. Yet the ripples certainly *seemed* to travel over the water. But no water has moved in a direction away from the centre. What was it that moved? The answer is—energy. Energy has been transferred from water drop to water drop along the surface, and it has been transferred in a peculiar way.

The transference has been made from particle to particle of water so that each particle is made to oscillate up and down. And as each particle is affected a moment after the one nearest to it (and nearer the centre) then all the water does not rise and fall at the same moment. It would be possible for one wave only to travel in such a way, just as a kink will travel along a rope. Usually there are many waves, separated from each other by the same interval of time.

We can get a picture of a single pulse travelling by making a toy of matchsticks. Let a number of these be arranged upright and side by side in a row, numbered 1, 2, 3, etc. If they are held firmly but not tightly in a framework, each match can be moved up or down. Then if we move one match up and down, and then number 2 is treated in the same way, and number 3, and so on in succession, we see apparently one match-stick travelling along over the rest. This is a very crude illustration, and the successive movements would have to be done very quickly to create the illusion.

The experiment can be improved. We can arrange the matchsticks to be resting on and along a cylinder which has on it a raised spiral ridge going once round the cylinder. Then if we rotate the cylinder one match-stick at a time is raised and lowered. Everyone with experience in trying to get over to pupils this rather tricky notion of a wave motion is familiar with some such mechanism which can help him.

The important first point for us to grasp is that the energy of a wave is handed on by making particles

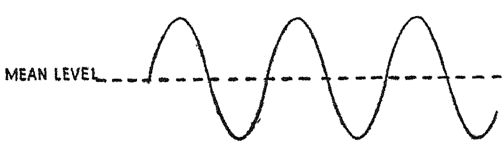

Fig. 1

vibrate in succession. In the first illustration we used, water ripples, these vibrations took place at right angles to the line of the wave's progress.

If we were to have a camera at the mean water level (*i.e.*, the level before any ripple starts to disturb the surface) an instantaneous picture would show, when the ripples are passing, a water outline of the shape indicated in Fig. 1. The distance from crest to crest (or trough to trough) of the ripples is called the *wave-*

length, and is a few inches in the case of water ripples due to the splash of a stone. If the energy is travelling at a constant speed or *velocity*, then this speed must be equal to the wavelength multiplied by the number of waves passing a fixed point every second (or minute or hour). The word used for this number is the *frequency*, and is expressed in *cycles per second* or if large in *kilocycles per second* (1 kilocycle=1000 cycles), or if very large indeed, in *megacycles per second* (1 megacycle=1000000 cycles). The statement made above about the velocity can be expressed as:

velocity=wavelength multiplied by frequency.

We can put letters in place of words and write letters together when we mean 'multiplied by' and we then get the arrangement:

$$v=f\lambda$$

which is the characteristic equation of a wave, where v=velocity, f=frequency and λ (Greek letter 'lambda')=wavelength. When using this equation we must be careful about the units we use. We cannot have the wavelength in feet and the frequency in cycles per minute and then expect to get the velocity in yards per second. The velocity would actually be in feet per minute.

If the derivation of this equation is at all difficult, we can make things easier by taking actual numbers. For example, if 10 complete waves pass a fixed point every second and if each wave is 5 inches long, then clearly 50 inches of wave must pass the fixed point every second. In other words, the wave velocity is 50 inches per second.

A wave need not be of the simple shape illustrated in Fig. 1. It can be much more complicated and appear, let us say, as in Fig. 2. This is not a picture of a water ripple. The test is *periodicity*. If energy is handed on by making a material vibrate and repeat its vibrations,

however complicated they may be, at regular intervals, then the resulting motion is a wave. For most purposes the simple shape of Fig. 1 is adhered to in explanations, the wave-form being taken to be what mathematicians call a *sine curve*, which is a picture of the equation y=sinx, the *sine* of x being a special function found from trigonometry tables. When x is O degrees, its sine is O, when x is 30 degrees the sine is ·5, when x is 60 degrees the sine is ·866, when x is 90 degrees the sine is 1, when x is 120 degrees the sine is ·866, when x is 150 degrees the sine is ·5, when x is 180 degrees the sine is O, when x is 210 degrees the sine is

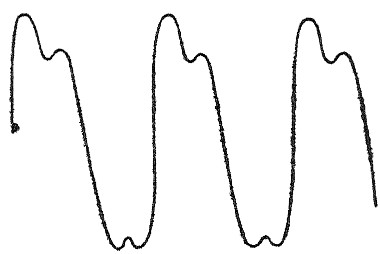

Fig. 2

—·5, when x is 240 degrees the sine is —·866, when x is 270 degrees the sine is —1, when x is 300 degrees the sine is —·866, when x is 330 degrees the sine is —·5, and when x is 360 degrees the sine is O, and as the angle is increased the values go through the same cycle for another 360 degrees, and so on. A diagram of these values would give us the simple wavy line of Fig. 1.

The reason for the sine curve being considered the simplest form of wave is mathematical, but even without this tool we can understand the general principles of the argument. Let us suppose that a simple pendulum is set swinging. It oscillates backwards and forwards, but its speed does not remain steady. At the end of the swing the speed is nothing, whereas at the bottom of the swing the speed is the highest of the

whole oscillation. This type of oscillation is called *simple harmonic motion*, and we find that anything set into oscillation by a shock executes this motion. If energy is handed on in a substance so that each particle makes simple harmonic motion, then the resulting wave-form is a sine curve, so this is the simplest wave-form we can have, being the result of each particle executing its natural oscillation due to one displacement only.

In addition to the periodicity and the equation mentioned, waves in general show other properties. They will, for example, show *interference*. This is easy to understand but not so easy to see convincingly demonstrated. Let us imagine a particle x of water acted upon by a wave A. At a particular instant let us imagine that the energy is just being handed on to the particle x to make it move upwards. Now let us suppose that another wave, B, is also moving in the water and that it reaches x just at this instant, but instead of tending to move x upwards, it tends to move it downwards. Then x will be acted upon simultaneously by two forces, one trying to move it upwards and the other trying to move it down. Its resultant movement will depend on the strengths of the pull due to A and B. If these pulls are equal, x will not move at all. This is complete *interference*. Thus one wave can wipe out another completely, if one is exactly half a wavelength behind the other and if the energy in each is the same. When one is 'behind' or 'ahead of' the other in time, the two waves are said to have a *phase difference*. If however A and B reach x *in phase*, so that each is trying to push x up (or down), then its movement will be greater than what it would be if acted upon by either A or B separately. This alternate cancellation and addition of the effects of two sets of ripples can be seen under favourable conditions when

the two sets are made on a pond by two stones. A criss-cross pattern of extra big crests and no crests at all can be seen.

Another phenomenon exhibited by waves is that of refraction. A wave will travel at a constant speed in one *medium*, *i.e.*, vibrating substance, but at a different speed in another medium. The change of speed occurs suddenly at the surface of separation of the two media, and the effect is to alter the direction of the wave if it is travelling obliquely to this surface, just as a rank of soldiers, wheeling, makes the one on the inside mark time and the others to travel at different speeds to keep the rank intact. This illustration is the wrong way round for our purpose, for the change of direction causes the change in speed of the soldiers, but if we imagine the soldiers to change their speeds by order first the result would be a change in the direction of march. When a small portion of a large wave strikes the surface of another medium, the part which strikes first is slowed down first, the neighbouring part next, and so on. The result is a change of direction.

Waves exhibit *reflection*, being turned back from surfaces of the correct quality, and when they are so reflected they obey the laws of reflection. We can see the reflection of water ripples from a wall. The regular use of the reflection of light waves by mirrors has made us familiar with this phenomenon.

But, it may be objected, why do we bother with these points? Water ripples can be seen. Let us leave the subject at that, some may say. But no, we must be patient, for although water ripples can actually be seen in shape, there are many waves which cannot be seen and their properties must therefore be inferred from the known properties of all waves.

We cannot, for example, see light waves, but light shows interference, reflection, refraction and other

wave phenomena. Light must therefore travel in waves, we say, because no other method of energy transfer would explain the phenomena. But if light is travelling in waves, there must be some substance which is vibrating (just as water does in the case of our ripples). Yet light will pass through a vacuum. How otherwise should we get light from the sun? So here we are up against a contradiction. If light travels in waves there must be a vibrating medium, yet a vacuum contains literally nothing. We have to get over this difficulty by *inventing* a medium which occupies all space, a medium which has never been detected by any sense or instrument. We call this invented medium the *æther* (or *ether* in more modern spelling) and we go on to say that light travels by waves in the ether. This cannot be regarded as a satisfactory description of the mode of travel, but what else are we to do?

The speed of light in a vacuum is 3×10^{10} (*i.e.*, 30000000000) centimetres per second, or about 186000 miles per second. The wavelength of the orange light given out by incandescent sodium vapour is ·00005893 centimetre. The need for specifying the colour will be understood when we come to deal with light in the chapter dealing with television.

Sound also travels in waves. But here we meet another difficulty. With water ripples we can see the waves. With light we can imagine ether vibrating at right angles to the line of the wave's progress. But with sound we have to leave visualisation and enter the realm of mathematical interpretation, because a sound wave is different. Yet it is a wave for it can show interference and refraction, etc.

The vibrating medium is definitely a substance, for sound will not travel in a vacuum, so we do not have to stretch our credulity. But the medium does not vibrate at right angles to the line of progress of the

wave: instead, it vibrates in this same line. We can get some help in imagining this by considering a field of corn when a breeze flits across it. Each head of corn is bowed away in succession from the breeze and then vibrates back, not to its rest position but a little further, and then goes forward again. In other words, the corn vibrates, but in the same line as the breeze. Yet the effect we see is that of a colour change (as the corn heads get close together or far apart) passing across the field.

We can still, however, *draw* the sound wave as though it were of the shape of the water ripples. This possibility leads us to consider this branch of mathematics—the drawing of pictures to represent relationships between varying but related quantities. In a word—*graphs.*

Most of us are familiar with simple graphs. We see them on the walls of the Underground Railway; we see them in the advertisement columns of the newspapers. These, however, are not the most useful ones for us, for they merely show disconnected sets of facts in diagrammatic form.

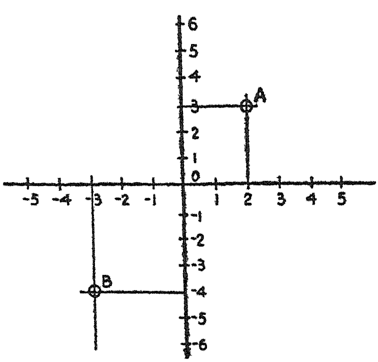

Fig. 3

For a graph we must have two reference lines, at right angles, called the *axes.* We fix any point by tracing lines from each axis and getting the intersection, just like fixing the position of a ship at sea by finding the latitude and longitude and then the intersection gives the exact position. Fig. 3 will show the method. All measurements are taken from the *origin* (O), the

point of intersection of the axes. On the horizontal axis, all measurements to the left of O are considered negative and all to the right positive. On the vertical axis, all distances up from O are positive and all downwards are negative. This is a convention accepted in the world of science. Let us call the upright axis, the y axis, and the horizontal one, the x axis. Then a point represented by $x=2$, $y=3$, would be fixed by finding the value $x=2$ on the x axis and tracing up a vertical line, and finding on the y axis the value $y=3$ and tracing along a horizontal line. Where the two intersect is the point required. It is marked A in the diagram. The point $x=-3$, $y=-4$, would be plotted in a similar way. This is called B in the diagram.

In practice we represent by scale on these axes the actual things we wish to graph. If the distances above or below the normal water level, in the case of our water ripples, are shown on the y axis and distances from the centre of disturbance on the x axis, we get a series of points corresponding to the instantaneous positions of the water particles. If we join these points we get a

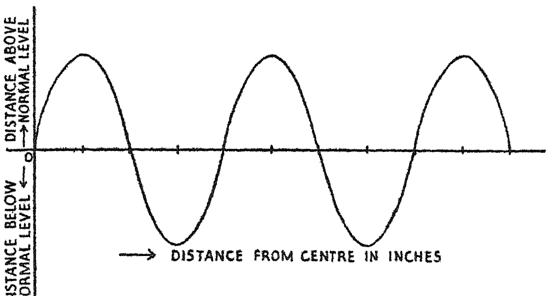

Fig. 4

picture like Fig. 1, only this time correct to scale. This is shown in Fig. 4. This is said to be a graph showing the relationship between the *displacement* of each particle and the *distance*. It is a displacement-distance

graph for water ripples. We can also plot the graph not of a practical experiment but of the relationship between two things given by an equation. If we do this with the equation $y=\sin x$, we get the sine curve, which is the same shape as Fig. 4.

We can apply the same method to any wave motion. With sound we can measure the displacement of each air particle from its normal, even though this displacement is in line with the wave. And we can plot displacements against the distance from the origin of the sound and we get a graph, if the sound is a pure tone, just the same in appearance as Fig. 4. Thus though we cannot *see* the wave as we can the water ripples nevertheless we can plot it on a graph and see the resulting curve.

If anyone should think that this is too abstract, let him examine Plate I. This shows actual photographs of the electrical variations due to sound in front of a microphone. The air pressure changes have been changed into electrical ones and these have been applied to a moving pencil of electrons hitting a fluorescent screen and making it light up where the pencil hits. The result is photographed. Let the doubter now forever hold his peace.

An interesting point is demonstrated in this picture, for we see that we can alter the scale on either of the axes to suit ourselves. The actual axes are not shown in the photograph. Another point which emerges is that in each case the sound does not give the simple sine curve mentioned above.

All this leads us to the subject of wireless waves. They themselves cannot be seen and must be interpreted by phenomena and graphs. They travel at the same speed as light, and they travel in the hypothetical ether. We must get out of the childlike, though interesting, habit of trying to visualise the phenomena,

and instead take the *curve*, if correctly drawn, as the basis of our understanding. But before we can consider wireless waves in detail we must understand the language of electricity.

CHAPTER II

ELEMENTARY FACTS ABOUT ELECTRICITY

WE do not know what electricity is, but we do know quite a lot about how to use it, witness our wireless communication, electric trains and trolley-buses, generators, etc. Any theory at best merely explains the mechanism in such a way that the explanation covers as much as possible of the observed mass of facts.

The present theory is that all matter can be divided ultimately into atoms. Any further division makes any one substance cease to exist as such, for each atom consists of a miniature system of electrons rotating round a nucleus. Each of these electrons is a particle of electricity. The sort of electricity held by the nucleus is different from that held by the electrons, and the nucleus is charged with its sort of electricity to an extent equal to that of all the electrons in order to balance them. If an electron is ejected from an atom this balance is disturbed and the atom strains to regain the lost electron. If on the other hand an atom gains an electron, it again is unbalanced and strains to get rid of the unwanted one. The same argument applies if an atom loses or gains more than one electron.

We can demonstrate the different character of the electricity on an electron and on the nucleus by a simple experiment. Let us take two very light little pills of pith and suspend them by means of silk threads. Now if we rub a vulcanite rod with fur, and then touch each of the pills with the rod, they fly apart, whereas if we touch one pill with the rod and the other with the fur,

they fly towards each other. This gives us the rule: *Like charges repel, unlike charges attract.*

If we succeed in charging up a plate with electrons and making another one deficient in them, they will be of opposite charge and if we connect the two by means of a substance which allows the electrons to flow, they do so. This flow of electrons constitutes an electric current. So we see that in order to get an electric current we must first create the state of strain mentioned above. This tendency to expel electrons from one part and attract them to another, is called *electrical pressure, electromotive force* (E.M.F.), or *potential difference.* We see then that we must have a potential difference before we can cause a current to flow.

In the early days of electrical theory this flow of something was noticed and in order to describe the direction of such a flow, words had to be adopted to indicate the difference between the end of a wire from which the electrons left and the end to which they travelled. The words used were *positive* and *negative*, and current was said to flow from positive to negative. The signs used for these respectively are + (plus) and — (minus).

When the electron theory came to the front, scientists discovered that the actual flow of electrons was opposite in direction to the conventionally accepted current direction. So the electron must therefore be negative according to the old wording, for a gain of negative is the same as a loss of positive, as may readily be understood if we consider negative electricity as a debt. A gain of a debt is the same as the loss of actual money equivalent in value. A man who suddenly acquires a debt of a shilling is that much worse off. So to-day we have the two contradictory notions that current flows from positive to negative, and that the electrons flow the opposite way. Both notions are correct and we

cannot simplify our theory by altering the old one for in that case the world's textbooks would have to be rewritten. The reader who wishes to understand the basic theory must therefore grasp both ideas. When considering valves we shall often have to think of electron flow as current.

We can revise our earlier explanation and say that an atom consists of a positive nucleus surrounded by a number of negative electrons. If an electron is lost, then that atom is positively charged. If it acquires an extra one, it is negatively charged.

When we are dealing with conditions wherein no current flows, we are dealing with a branch of the subject called *electrostatics*. The quantity of electricity in a body is called the *charge*, and the *potential* is the state of any body in the electrostatic field, *i.e.* the region in which the electric forces operate. We measure potential by difference and so get the expression *potential difference* or p.d., and this expression is used also in connection with current electricity. If a body A has a potential of 60 units and another, B, has no potential, then the p.d. is 60 units. If A has 60 positive units and B has 60 negative units then the p.d. is 120 units, and A is positive with respect to B, and B is negative with respect to A. These two statements would apply to the first case also if the potential of A is 60 *positive* units. In wireless work we are concerned chiefly with current, but nevertheless there are aspects of theory which can be described only in terms of electrostatics.

CIRCUITS.—Anyone who has ever handled any electrical apparatus soon becomes aware that always for current to flow there must be a complete bridge across the two points between which a differential of potential exists. Even when we switch on an electric lamp we are utilising this fact. The switch is a device for bridging a gap in the wire. From the switch one wire goes to one

end of the lampholder and so to the lamp, and from the other connection of the lamp a wire goes back to the main supply. The free end of the switch is also connected to the supply. When we switch on, therefore, we make a complete connection from one end of the main supply to the lamp, through it, then to the switch and thence back to the supply.

The name given to this complete bridging of the supply is *circuit*. We must have an electric circuit in order that current shall flow, and one part of that circuit must be a source of potential difference.

There is a method of drawing electrical circuits with which we must become familiar. It is a sort of shorthand, certain conventional signs being always used to represent certain pieces of apparatus or *components*. We

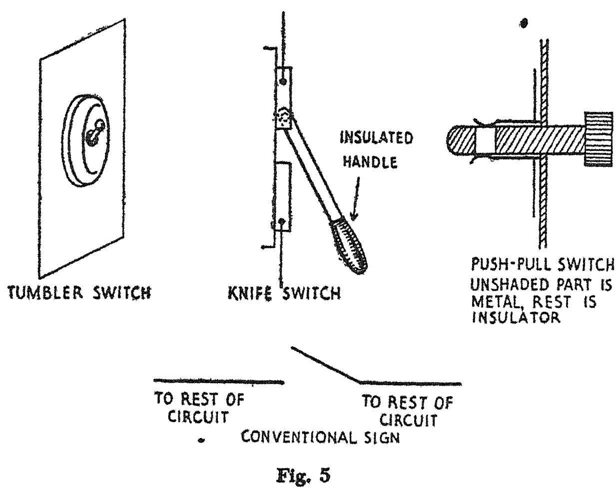

Fig. 5

do not usually show the actual appearance of a component. In Fig. 5 are shown several sorts of switch, and with them the conventional sign for a single-pole single-throw switch (for a switch can make or break numbers of circuits according to its design). The ordinary single lamp circuit is shown in the conventionalised

manner in Fig. 6, the nature of the supply not being shown.

The parts of the circuit which connect the various components must be of a material which allows electricity to flow easily. Such a material is called a good *conductor*. A material which hardly allows current to flow at all, and in fact refuses it entirely at low electrical pressures, is called an *insulator*. The best conductor is silver, and the second best is copper which is far cheaper, so we find that all ordinary wiring is done with copper wire. It is insulated with silk or rubber or cotton or enamel, or several of these. This insulation is to prevent the accidental creation of new circuits by touching, and to prevent anyone touching a live wire from being injured. Glass, ebonite, the new synthetic resins such as bakelite, and porcelain are also insulators.

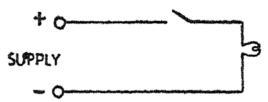

Fig. 6

A special sort of wire is called *twin flex*, consisting of two ropes of fine copper wire twisted together and insulated to make a very flexible connector. The wire used for connections inside a wireless set is usually coated with tin to facilitate soldering and prevent corrosion. If these connections are rigid there is no need to insulate the wire used. Telephone overhead wires are made of bare copper. Overhead cables for distributing the high-pressure supplies of the national grid systems are made of steel-cored aluminium.

Electrical Units.—Before we can proceed far in electrical work we have to make measurements, and for these we must have units of fixed size, just as all our measurements of length are comparable to a standard yard. The unit of electrical pressure, potential difference, or E.M.F., is the *volt*, so we sometimes use the word *voltage* for any of these quantities. The unit of the rate at which electricity flows, *i.e.* the current, is the

ampere. The rate at which work is done or energy consumed is called the power, and the electrical unit is the *watt.* The ability of a component or conductor to oppose the flow of electricity is called its *resistance*, the unit of which is the *ohm.* There is an abbreviation for each of these:

volt	V.
ampere	A.
ohm	Ω (capital Greek letter 'omega').
watt	W.

In wireless work these units are often too large, so necessitating the use of very small fractions which are a nuisance. So we subdivide the units to make smaller ones by means of prefixes. The prefix *micro-* means 'a millionth of', and so three microamperes are really three-millionths of an ampere. The abbreviation for this is μ (the Greek letter 'mu'), and so

μA. =microampere,
μV. =microvolt,
μW. =microwatt (rarely used),
μ Ω =microhm.

The prefix *milli-* means 'a thousandth of' and is used in the same way as micro- with the abbreviation m, *e.g.* mV.=millivolt.

Sometimes in electrical engineering the ordinary unit is too small and so again we create new units, this time larger than the original. The prefix *kilo-* means 'a thousand' and so three kilowatts (3 kW.) are three thousand watts. The prefix *mega-* means 'a million', and from this we get the unit 'megohm', written shortly M Ω., which is a million ohms.

These prefixes can be applied also to other units than purely electrical ones, such as the frequency of waves, for example. So we get the expressions used in Chapter I, such as 'kilocycles per second' (kc/s) and 'megacycles per second' (Mc/s).

Instruments are needed for measuring electrical pressure (or p.d. or E.M.F.), electric current, and so on. The *voltmeter* is used for measuring the pressure, or rather the millivoltmeter if it is required to read in the small units mentioned above. An *ammeter* is used for measuring the current in amperes, or a milliammeter or microammeter to read the current in the smaller units. Each is shown by means of a circle. Inside the circle is written the letter showing its purpose, as shown in Fig. 7. The straight lines joining each circle are to show the connections to the circuit. All the straight lines in circuit diagrams indicate the connecting wire

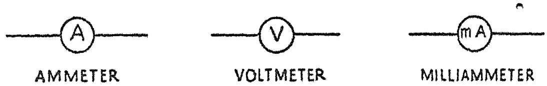

Fig. 7

assumed to have no resistance and therefore not to affect the circuit but merely to act as connecting links.

Sources of E.M.F.—In the simple experiment mentioned above with a piece of fur and a vulcanite rod, we had a means of creating electrical potential difference. Of all the ways of doing this to-day the oldest is due to chemical action. Two plates of metal are immersed in a solution of some salt or acid. For example, copper and zinc can be put in dilute sulphuric acid. This makes a *cell* with an E.M.F. of just over one volt. It has a great disadvantage, and that is that when current is driven by it the chemical action soon backfires and the E.M.F. drops to an unusable value. To overcome this we must put in this cell a *depolariser*. There are several sorts of cell with depolariser, but the commonest one is the Leclanché cell. This has a carbon strip inside a mass of granules of manganese dioxide. All this stands in a porous pot. Outside this pot is a solution of sal-ammoniac (*i.e.* ammonium

chloride) in a large jar. In this solution stands a zinc rod. The carbon is the positive 'pole' of this cell and the zinc is the negative 'pole'.

The *dry cell* is a very convenient adaptation of the Leclanché. The sal-ammoniac solution is made into a paste with gelatine and plaster-of-paris, the porous pot is replaced by a linen bag, and the container is a zinc cylinder, thus serving as container and negative pole. The top is sealed with pitch. This so-called dry cell is not really dry and is in fact useless as soon as it dries out. It gives an E.M.F. of 1·5 volts. Both it and the Leclanché cell have the disadvantage that the chemical action tires fairly easily and so they are useful only for intermittent work such as lighting a flash-lamp or ringing a bell. After a rest the E.M.F. is up again to full strength.

The *accumulator* or *secondary cell* is rather different, for it has the great advantage of being chargeable. When a dry cell ceases to act it is dead, but when an accumulator runs down it can be recharged. It consists of two groups of plates (or merely two plates in a simple one), one group being lead-coloured and the other being dark brown (lead peroxide). The positive pole is the brown group and is usually connected to a red terminal on the top of the container. The liquid is sulphuric acid. As the accumulator is used up the brown plates turn lighter in colour and the negative plates darken. At the same time the specific gravity of the acid (*i.e.* the relation of its weight to the weight of the same volume of water) falls, and when recharging is done by connecting a supply to the accumulator the original colour of the plates is restored and the acid specific gravity comes up. When fully charged the specific gravity is 1·25 and when completely discharged, 1·1. The E.M.F. of such a cell is 2·2 when fully charged but it soon settles down to 2·0 volts. The advantages of this cell

are that much larger currents can be taken from it than from a dry cell and, of course, that it is renewable.

A *battery* is a combination of cells. If we have three dry cells and connect them so that the zinc of one is connected to the carbon of the next, the zinc of this one to the carbon of the third, one free zinc at one end and a free carbon at the other being left for circuit connections, we get the well-known flash-lamp battery giving 4·5 volts, exactly three times the E.M.F. of each cell. The method of showing a cell and a battery of three cells connected in the way described is given in Fig. 8.

The other way of producing an E.M.F. is by the use of a generator or an alternator. Such a machine is

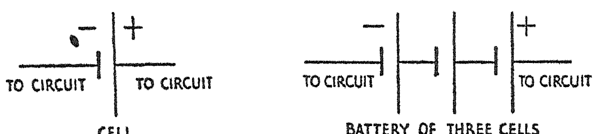

Fig. 8

driven by coal or oil which gets its energy from the sunlight of thousands of years ago. So really switch on a portion of very old sunlight. The supply which comes from the generator or alternator will soon be standardised all over England at 230 volts. It is brought to cables in the streets and thence to the houses. In each house the supply is connected to the various sockets on the walls or else to ceiling roses, for use for power, heating or lighting. A switch is incorporated in each separate circuit from the 'mains'.

A special feature of the mains supply is that each circuit is supplied with a *fuse*, which is a piece of wire which will melt or 'blow' when the current gets so high as to be dangerous to the wiring. Thus the circuit is broken and the supply automatically cut off. When this happens it means that either a temporary 'short circuit' has taken place or one more permanent

due to some fault in the apparatus being used. The remedy is to disconnect the apparatus, switch off the mains, replace the blown fuse with the correct fuse wire, and then examine the apparatus for faults. If the 'short' was temporary, then the circuit will function again, but if the apparatus is faulty the fuse is likely to blow again as soon as the circuit is switched on with the apparatus connected.

The mains supply is the most efficient source of electrical energy and is to-day used more and more for wireless sets instead of batteries.

Series and Parallel.—There are two ways of connecting components in a circuit. If they are connected end to end, leaving one terminal of one at one

Fig. 9

end and the opposite terminal of the last at the other end, both free for connection to the circuit, they are said to be in *series*, as were the cells connected in the way described above. But we can connect two or more components together differently. Let us consider cells again for an example. If we connect the two positive poles together, making a special connection to be left free for joining to the circuit, and if we connect the two negative poles together in a similar way, the two are said to be in *parallel*. The two cells so connected will give the E.M.F. of one cell only, but they will drive a bigger current without running down.

All components have not negative and positive poles, but they have two or more *terminals* by means of which the connections are made to the circuit. These terminals usually have screw tops so that we can unscrew, insert the bared end of the connecting wire, and screw down

again. Even though components have not specifically labelled positive and negative poles they can still be connected in series or parallel. Resistance is shown in diagrams by means of a zigzag line. Fig. 9 shows two resistances connected in series and two connected in parallel to illustrate the description above. The word *shunt* is often used instead of parallel when we describe the method of connection of components.

We have previously spoken of resistance as a property of a circuit or component, but we often need resistance of known value and then we use a component made of high-resistance wire or of composition. Strictly speaking it should be called a *resistor*, but in the loose manner in which we adopt names and stick to them the word *resistance* has come into use both for the property and for a component having that property.

A *high-tension* battery for wireless purposes consists of many dry cells in series. For example, a 108-volt H.T. battery has 72 dry cells. The *grid-bias* (G.B.) battery has either six or else eleven cells in series giving 9 or else 16·5 volts.

A voltmeter is always connected in parallel with the part of the circuit across which we wish to measure the potential difference. If it is connected in parallel across the source it measures the whole E.M.F. supplied. If it were connected in series in a circuit it would read merely the p.d. across its own terminals. An ammeter, on the other hand, is connected in series in a circuit, and it does not matter where because the current has the same value in any part of a series circuit. When so connected the ammeter measures the current

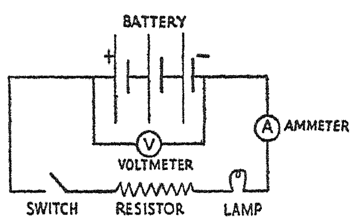

Fig. 10

value of the circuit in series with it and not the current value in any separate parallel branch of the whole circuit. In Fig. 10 is shown a complete circuit of three cells in series, an electric lamp, an ammeter, a voltmeter (to measure the battery E.M.F.) a switch and a resistor.

OHM'S LAW.—There is a relationship between the potential difference across a part of a circuit, the resistance of that part, and the current flowing through it. The relationship is called Ohm's Law. Put in the form of algebra, if I=current, E=p.d. and R= resistance:

$$I=\frac{E}{R}$$

$$\text{or}\quad E=IR$$

$$\text{or}\quad R=\frac{E}{I}$$

Anyone who knows any algebra will recognise that these three are all varieties of the same equation.

We can express it in words by saying that the current is equal to the p.d. divided by the resistance, or that the p.d. is equal to the current multiplied by the resistance, or that the resistance is equal to the p.d. divided by the current. We use whichever form we need. For example, if we wish to find the resistance we use the last form, as: if we know that a 230-volt lamp takes $\frac{1}{4}$ ampere, then its resistance must be 230 divided by $\frac{1}{4}$ which comes to 920 ohms.

In using this law we must be careful about our units. If the current is in amperes and the resistance is in ohms then the p.d. is in volts. But if in using the second form of the equation, let us say, we were to multiply current in milliamperes by resistance in megohms we should not know what units to call the

resulting potential difference. They would actually be kilovolts because a milliampere is a thousandth of an ampere and a megohm is a million ohms. It is safer to see that all the quantities used are in units of similar size. For example, we can work in milliamperes, millivolts and milliohms, or in microamperes, microvolts and microhms, or in amperes, volts and ohms.

Let us consider more examples. An E.M.F. of 20 volts is supplied to a circuit having a resistance of 5 ohms. Then the current value will be 20 divided by 5=4 amperes. Another: current of 5A. flows through a circuit. One resistor has a value of 10 ohms, and the only other component (in series) has a resistance of 20 ohms. What is the E.M.F. supplied to the whole circuit? Well, the p.d. across the resistor is 10 multiplied by 5=50 volts, and the p.d. across the other component is 20 multiplied by 5=100 volts. Therefore the total E.M.F. is 50 plus 100=150 volts.

Heating Effect.—When electricity flows energy is expended in overcoming the resistance. This appears in the form of heat. In many appliances to-day we make use of this to heat water or cook food or warm a room, but even if we do *not* wish to use the heating effect we always get it. We can minimise its danger by making the wire of large enough diameter and allowing air circulation, but we cannot get rid of it. We can go further, and say that whenever heat is caused in any electrical circuit, energy is being consumed.

Electrolysis.—When a moist chemical is made part of an electrical circuit, changes occur in the chemical owing to the passage of current. This is utilised in electroplating. The action is termed *electrolysis*. The aspect of this phenomenon interesting to wireless students is that we sometimes get electrolysis when we do not want it, as for example when an earth connection is made which carries minute current from a

battery. If the earth is moist electrolysis may in time ruin the metal joints.

SERIES AND PARALLEL AGAIN.—Now that we have gained some knowledge of components and of Ohm's Law we can return to this subject again. Let us consider the circuit of Fig. 11. If the resistors in the two

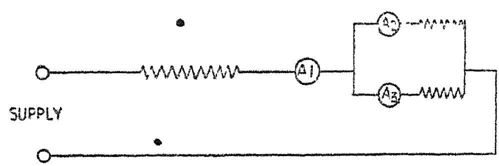

Fig. 11

parallel branches are different in value then the readings of A_2 and A_3 will be different. But they will add up to be equal to A_1. We express this in words by saying that the currents in parallel branches add up to be equal to the main current.

Now let us consider the circuit of Fig. 12. If we make up a circuit like this we find that if the resistors are different in value then the readings of V_1, V_2 and V_3

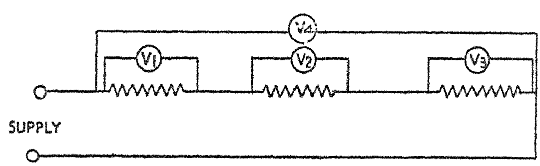

Fig. 12

will be different, but they add up to a value equal to that shown by V_4. This is expressed in words so: The potential difference in series portions of a circuit add up to make the total potential difference.

There are two other cases. The first is of current in series portions of a circuit. In this case, as stated before, it does not matter where the ammeter is it will give the same reading. The other case is when we put a volt-

meter across the separate parts of a parallel circuit. Then we find that the p.d. is in each case the same.

Another interesting point arises from a consideration of the circuit of Fig. 12. If the resistors have the values 10 ohms, 20 ohms, 15 ohms, from left to right, then we find that the voltmeter readings are in proportion to these values. If the total voltage is 135, then V_1 reads 30V., V_2 reads 60V., and V_3 reads 45 V. In other words, the 'voltage drop' in any part of a series circuit is in proportion to the resistance of that part.

We must also consider the equivalent effect of resistance in series and in parallel. In the first case, series, it is simple. All we have to do is to add up the separate resistances. For example, two resistances of 20 Ω and 50 Ω in series will have an equivalent effect of 70 Ω. The parallel case is a little different. The same two resistances in parallel would have an equivalent resistance of 14·3 ohms. This is obtained from the equation

$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\text{ etc.}$$

where R=equivalent resistance and R_1, R_2, R_3, etc., are the separate resistances in parallel. The calculation from this is a little tricky. For example, in the case quoted if R_1=20 ohms and R_2=50 ohms, we have

$$\frac{1}{R}=\frac{1}{20}+\frac{1}{50}$$

$$=\frac{5}{100}+\frac{2}{100}=\frac{7}{100}$$

Therefore $R=\frac{100}{7}=14{\cdot}3$ ohms.

We can note that this is less than either of the branch resistances. This is understandable, for by putting two resistances in parallel, we are in effect increasing the

area through which the current can flow and so we are decreasing the resistance.

This leads us to an application. We can arrange a circuit like that of Fig. 13. If the resistance AB is 100 ohms, and if CB is 60 ohms, then the p.d. across CB will be 3/5 of the p.d. across AB. This method is sometimes used to get a smaller voltage from a large one. We 'tap' off the voltage required. It is the method of the *potentiometer.*

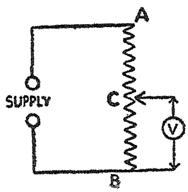

Fig. 13

But several points emerge from a little thought about such a circuit. If the resistance of the voltmeter shown is low, then the combined effect of the resistance CB and of the voltmeter in parallel will be much less than that of either. Consequently the total resistance AB is less and the proportion CB is altered. So we cannot use the potentiometer method if the tapped voltage is to be applied to a circuit of low resistance. Also we see that a voltmeter must have a high resistance if it is not to affect in any noticeable degree the actual p.d. it is used to measure. A good voltmeter has therefore high resistance, the 'good' value being 1000 ohms per volt of the scale, so if an instrument is to read to a maximum of 120 volts it should have a resistance of 120000 ohms.

The word *shunt* is often used for the parallel connection as observed earlier in this chapter. We speak of shunting a component with a resistance. A little arithmetic applied to the parallel resistances equation will show us one use of a shunt. Consider the circuit of Fig. 14. The p.d. across AB applies equally well to

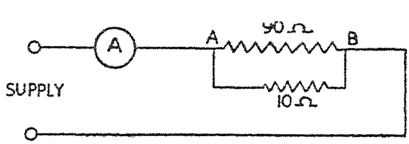

Fig. 14

the 90 ohms resistance or to the 10 ohms one, because the p.d. is that fraction of the whole corresponding to the proportion of the whole resistance held by the equivalent resistance of the two in parallel. If this p.d. is 180 V., then the current through the upper branch is $\frac{180}{90}=2$ A. The current through the lower branch is $\frac{180}{10}=18$ A. The reading of A is therefore 20 A. So we see that the effect of shunting a resistance by a much smaller resistance is to divert most of the current through the latter.

We see also that if there were an ammeter in the upper branch of AB it would register 2 A. whereas the main current is 20 A. This gives us a method of using an ammeter for reading currents larger than its scale shows. Any ammeter has resistance, and so by choosing the correct value of shunt resistance to connect across the ammeter in parallel, we can make the instrument read to whatever maximum we like *larger* than its fundamental range.

For example, if the ammeter resistance is 10 ohms and its maximum scale reading is 5 A. then if we shunt it with another resistance of 10 ohms, when it reads, say, 3 A. the real main current will be 6 A. and so the maximum reading of the main current is 10 A. Of course the current through the actual ammeter coil is still what it would normally be but the main current represented by the reading is twice that because half of it is being shunted through the extra parallel resistance. We can arrange a number of shunts all connected at one end to the ammeter but with the free ends connected to sockets into which we plug the other ammeter connection according to what range we wish to read. Then we have a multi-range ammeter, a very useful instrument. In Fig. 15 is shown the arrangement

of a multi-range milliammeter. If the instrument resistance is 100 ohms and it reads up to a maximum of 20 mA. then shunt 1 of 100 ohms would enable it to read up to 40 mA., shunt 2 of 25 ohms would make it read up to 100 mA., shunt 3 of 11 ohms would enable it to read up to about 200 mA., and shunt 4 of 2 ohms would bring the range up to 1000 mA. or 1 A.

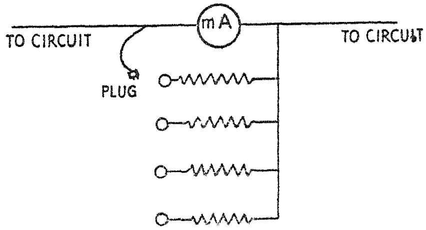

Fig. 15

This multi-range principle can be extended to voltmeters as well, only we are no longer concerned with extra resistances in parallel. Instead, they are in series. For instance, if a voltmeter has a resistance of 1000 ohms and another resistance of 1000 ohms is in series with it, then it will read only one half of a p.d. applied across both voltmeter and resistance. A number of series resistances can be arranged on tap.

A combination of both series and shunt resistors available by means of plugs and sockets enables us to use a low-reading instrument as a multi-range instrument both for current and p.d. The scales corresponding to the several shunts and series resistors are marked on the one dial. A number of these multi-range instruments is on the market.

We cannot apply the same methods to make a comparatively insensitive instrument read to a *lower* maximum.

The method of calculating resistance in series and in parallel brings us to another fact. We know that resistances in series must be added together to make the equivalent resistance. This shows us that the longer a conductor is, the greater will be its resistance. Re-

sistances in parallel have a smaller resistance than any one of the separate ones. This brings us to realise that if we make a conductor bigger in cross-sectional area, then its resistance is decreased. The resistance also depends on the nature of the material. All these facts are incorporated in one equation:

$$R = \frac{\rho l}{a}$$

where R=resistance in ohms, l=length in inches, a= cross-sectional area in square inches, and ρ is a figure called the *specific resistance* of the material, usually expressed in microhms per cubic inch (or perhaps per cubic centimetre, in which case we must put l in centimetres and a in square centimetres), though it must be expressed in ohms if R is to come out in ohms. Example:

length of copper wire 20 feet
cross-sectional area ·001 square inches
ρ for copper= ·67 microhms per cubic inch.

$$\text{Then R (in ohms)} = \frac{\cdot 67 \times 10^{-6} \times 20 \times 12}{\cdot 001}$$

$$= \cdot 67 \times 24 \times 10^{-2} = \cdot 1608 \text{ ohm.}$$

It should be noted that $\cdot 67 \times 10^{-1}$ is a convenient way of writing '·67 divided by a million'. Students of algebra will readily understand the method. We divide by a million to bring the microhms to ohms.

Wire for electrical purposes is expressed very often by numbers. We talk of Standard Wire Gauge (S.W.G.) number 40, and so on. The diameters of the wire decrease as the gauge numbers increase. Thus the diameter of S.W.G. 20 is ·09144 cms. whereas the diameter of S.W.G. 40 is ·01219 cms., less than a seventh of the diameter of number 20. Flex is usually designated by the number of separate strands and the

diameter of one strand, as: 14/·0076 meaning 14 strands of diameter ·0076 inch.

THE EARTH.—The earth is a poor conductor of electricity. That is to say, its specific resistance is high. But there is a lot of it, and so the effective resistance of

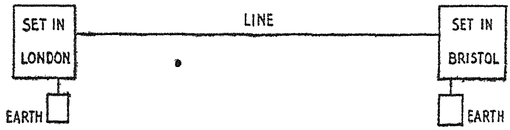

Fig. 16

the earth between two points is low, and for ordinary purposes the earth thus becomes a good conductor. So we can use it instead of a wire in a telephone or telegraph system. Thus the diagram of Fig. 16 could represent a telephone circuit.

In addition, as the earth is so large it can be assumed to be at zero potential. So there is always a potential

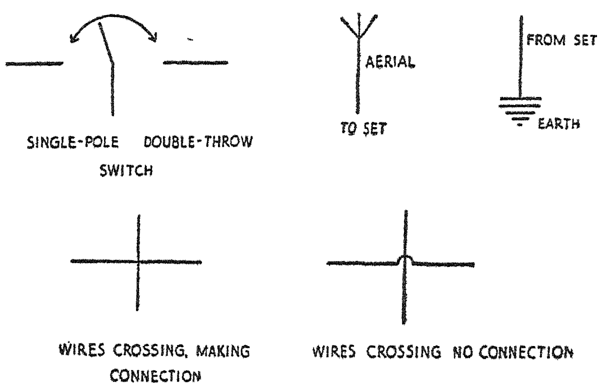

Fig. 17

difference between a charged body and the earth. If the charged body by some mishap is connected to the earth, the charge is said to be 'earthed'. This makes it dangerous for a person to stand on the ground and touch any live wire or cable, for the person makes the

connecting link for what may well be a current large enough to kill. Water in a bath is connected to earth *via* the pipes, so a person in a bath is particularly liable to electrocution if he sits or stands in his bath and touches an electric fire or lampholder.

In Fig. 17 are shown several of the drawing symbols used for electrical components and connections, including the one used to show the 'earth'.

ALTERNATING CURRENT.—Up to the present we have considered that one end of the source of electricity is positive and the other negative. The current which flows is thus uni-directional, and is known as *direct current* (D.C.) There is another sort however.

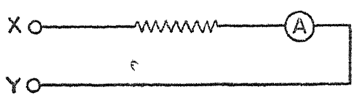

Fig. 18

Consider the circuit of Fig. 18. If the current flows all the time in the direction XY through the circuit, it is direct. But if it flows from X to Y and then reverses and flows from Y to X, it is *alternating current* (A.C.) Ordinary A.C. does flow like this and at the same time alters in value so that if the alternations are slow enough, one per minute, let us say, the ammeter shows an increasing current up to a certain figure depending on the voltage of the supply and the resistance of the circuit, and then a decreasing current to zero. Then it increases again, in the opposite direction, to the same maximum value, and decreases to zero, and then the whole process is repeated. Each complete set of changes is a cycle and we get the same unit for the frequency as we did for waves in Chapter I, *viz*, cycles per second. The graph of a simple alternating current is a sine curve.

The ammeter has to be a special one with centre zero for it to show current in each direction because the ordinary ammeter has its zero on the extreme left of the

scale and so can indicate a flow in one direction only. Actually, the alternations of a really practical A.C. are so rapid that even a centre-zero ammeter indicates no current whatever. So a special sort of ammeter has to be used for A.C. measurements. Most domestic supplies will eventually be A.C. and the frequency of such supplies will be standardised at 50 cycles per second. In wireless work, however, we have to deal with alternating current of frequencies as high as several megacycles per second. More detail about alternating current will be given in Chapter III.

Resistors.—Some components are made which have high resistance. If they are made of wire then it is not copper but instead a high-resistance alloy, such as eureka, manganin, or nickel-chrome. One type of resistor is flexible and held in an insulating flexible cylinder. The ends of the wire are soldered to 'spade' terminals for ready connection to other components. But there are other resistors not 'wire-wound' but instead made of high-resistance compound such as graphite.

A very necessary component for wireless work is a *variable resistor* or *rheostat*. Its commonest form is that of a rotating knob controlling a contact on a wire-

Fig. 19

wound circular ring. Any variable resistor is shown in diagram in one of the ways indicated in Fig. 19. In the method shown on the left of the figure we can readily see that the resistance in the circuit is that between A and B, and that the portion BC is not in the circuit at all. By varying the position of the contact B we can alter the length of AB and so alter the resistance in the

circuit. The method indicated on the right of the figure does not show the contact but merely shows that the resistance value can be varied.

MAGNETISM.—Magnetism is a property known for centuries to be possessed naturally by certain iron ores and by meteorites. It is also possessed by iron and iron alloys after special treatment. It is a peculiar property. If we put a magnetic substance near iron or an iron alloy we get attraction at once. In popular language, a magnet will 'pick up' nails and other iron things. Iron is the only element thus affected to any important extent. We can make a steel needle into a magnet by stroking it regularly in the same direction repeatedly with another magnet, natural or artificial.

If we suspend this magnetised needle we notice a peculiar fact—it sets itself after any disturbance in exactly the same direction, approximately north and south. In the mariner's compass we have made use of this fact for hundreds of years. Not only does the needle set itself north and south but the same end always points north. This shows that the two ends are not the same magnetically. The end which points north is called the north-seeking pole and the end which points south is called the south-seeking pole, both being usually abbreviated to north pole and south pole.

If we have another magnetic needle and hold it in the hand and point its north-seeking pole towards the north-seeking pole of the suspended needle, the latter will swing away. If we point the south-seeking pole of the held needle towards the north-seeking pole of the swinging needle the latter turns towards the one in the hand. The first action is repulsion and the second one is attraction. Two south-seeking poles also show repulsion. The rule is therefore: like poles repel, unlike poles attract. This rule is similar to that for electrostatic charges. Any piece of iron will show the attrac-

tive effect on *either* end of a magnetic needle, but only another magnet will show the repulsion effect. Another fact we must remember is that only the materials which are affected by a magnet can be magnetized. They are iron and its alloys. We cannot make a magnet of copper or zinc or any other metal.

A bar magnet is a straight and narrow piece of steel magnet. A horse-shoe magnet is the same thing bent round so that the two poles are very near each other.

THE MAGNETIC FIELD.—If we put a small iron nail or needle on a piece of paper and hold a magnet underneath this paper we can control the nail or needle. The force acting between magnet and nail is not affected by the presence of the non-magnetic paper in between. Or if we hold a strong magnet in the hand and approach a nail resting on the table, when the magnet is near enough the nail jumps to meet it. Something is obviously happening in the space between nail and magnet. A tiny magnetic needle put in this space is very much upset until at last it ceases to oscillate and settles down in a direction depending on the polarity of the magnet. This space in which the magnetism is acting is called the *magnetic field*. The force in this field acts along certain well-defined lines. We can find the position of these lines for a bar magnet by putting a small magnetic needle in various positions near the magnet and marking two points corresponding to the ends of the needle. If the points are joined up afterwards with a pencil line we have a map of the *lines of force* in the magnetic field. They are shown for a bar magnet in Fig. 20. They are continuous through the magnet itself, indicated in the figure by dotted lines.

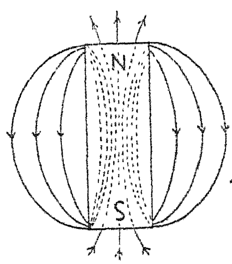

Fig. 20

The conventional direction given is that where they come out is a north pole and where they go in is a south pole. The unfinished lines represent loss of energy. The more closely packed the lines of force are, the more intense is the magnetic field. In Fig. 21 the field of force of a horseshoe magnet is shown, and we see that the field is much more intense for this than for a bar magnet. The external lines only are shown. Even with a horseshoe magnet some lines are lost and so it is the practice to put a small 'keeper' of iron across the poles to concentrate the lines and save loss of energy.

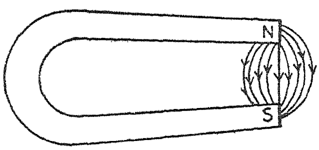

Fig. 21

The number of lines per square inch or per square centimetre is called the *flux density*, and one line per square centimetre is known as one *Gauss*. The total number of lines in any space is called a number of *Maxwells*. Thus 20 Gauss means 20 lines per square centimetre (of cross section) whereas 20 Maxwells means 20 lines of force altogether in the district under consideration.

Iron or an iron alloy has the ability to concentrate the lines of force inside itself as shown in Fig. 22, and

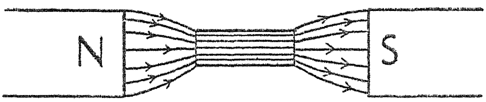

Fig. 22

the different sorts of iron or iron alloy have different abilities in this respect. The measure of this ability is called the *permeability*, and is the ratio of the number of lines of force it will take to the number in the same cross-sectional area of air. Mu-metal is a special alloy with a remarkably high permeability. The earth is a

gigantic magnet and that is why a magnetic needle will swing approximately north and south. Mu-metal is so permeable that by holding it in a line north and south, it concentrates so many of the earth's lines of force in it that it will act as a magnet. This is the only metal to exhibit magnetisation by means of the earth's magnetic field.

A brief consideration of Fig. 22 will show why a piece of iron is attracted by a magnet. The iron has lines of force entering and leaving and so is for the time being a magnet of opposite polarity to the magnet nearby. So the result is attraction.

We must not rashly conclude that our aim is only to get an iron alloy of high permeability. That is not always good, for we may want the metal to retain its magnetism, and high permeability does not go with high retentivity. Silicon and nickel are two of the elements used to alloy iron to make products of special magnetic properties.

Electromagnetics.—Just over a hundred years ago several scientific investigators, including Oersted, Ampère and Faraday, showed that there was a connection, previously unknown, between magnetism and electricity. The two effects shown were (a) magnetism could be created by means of electricity, and (b) electricity could be made by means of magnetism. These two facts are fundamentally responsible for the advances in electrical engineering of a hundred years past.

We can show quite simply the first of the two facts above. Let us have the circuit of Fig. 23. The spiral line indicates a coil of wire. If we point this coil towards a magnetic needle and switch on, we find that the coil acts just as if it were a bar magnet. The coil

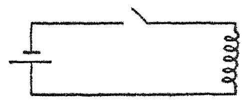
Fig. 23

must be long and narrow for this effect to be seen, a shape known as a *solenoid*. If iron is placed inside it the effect is tremendously increased. Such an arrangement is an *electromagnet*. Powerful ones are used in industry for picking up tons of scrap iron.

The strength of the electromagnet is directly proportional to the product of current and number of turns. This product is called the ampere-turns. Thus 2 A. flowing in a solenoid of 100 turns would produce 200 ampere-turns.

Anyone who wishes can make an electromagnet with a little double-cotton-covered (D.C.C.) No. 24 wire, a few nails (for core), and a flashlamp battery. Such a magnet will pick up needles and iron filings. A better design of electromagnet is the basis of the telephone receiver. We must note that, except for slight residual magnetism, the effect ceases when the current no longer flows. But if the core is made of high retentivity it can be made into a permanent magnet by using this residual magnetism if high ampere-turns are used. This is the modern method of making magnets. Any iron or iron alloy magnet which has been so made is called a *permanent* magnet to distinguish it from the temporary electromagnet.

The ammeter and voltmeter both depend on electromagnetism for their functioning. Anyone can make a very simple current detector. It is but necessary to wind a coil, not a solenoid but a flat coil, and suspend a magnetic needle at the centre of the coil. Then when current flows in the coil the needle moves as a result of the interaction between its own magnetic field and that created by the current in the coil.

In practical instruments, the current is made to flow through wire wound round pole pieces so that the current creates a straight, intense, magnetic field. A piece of iron in this field will move. It will indicate

current in either direction. It is a moving-iron instrument. If instead of a piece of iron we have a moving magnet then the instrument will read current in one direction only.

A much better instrument is the *moving-coil* ammeter or voltmeter. With this there is a permanent magnetic field. In it floats a light moving coil of very fine wire with a pointer attached. Current is made to flow through this coil and the consequent movement of the pointer is an indication of the size of the current. The motion is directly proportional to the current.

The reader may get the impression that an ammeter is just the same as a voltmeter. Fundamentally this is true because both depend on the strength of current to operate the indicator. But with a voltmeter the resistance should be high. If we use a sensitive milliammeter of, say, 20 ohms resistance, and put in series with it a resistance of 980 ohms, then the total resistance is 1000 ohms. Then if we pass current which registers 2 mA., the p.d. across all this resistance must be $2 \times 1000 = 2000$ mV. or 2 V. So we can mark 2 V. on that part of the scale. By varying the current we can get a new scale of volts, if the 980 ohms resistance is always in use. We can even use the instrument both as milliammeter and voltmeter if we arrange different terminals for the voltmeter use, incorporating the extra series resistance, and if we have a double scale, one for milliamps. and one for volts. We now understand how it is possible to have one instrument with a choice of series resistances and shunts to give a multi-range instrument both in milliamperes and volts.

The second effect (b) above, *viz*, that magnetism can be turned into electricity can also be demonstrated. A very long solenoid of many turns is connected in series with a milliammeter, making a complete circuit. Now plunge a bar magnet into the coil lengthwise and the

needle of the instrument kicks over and returns to zero. The very fact that it has moved shows that electric current flows. Now remove the magnet, and a kick in the opposite direction will be observed if the milliammeter is of the centre-zero type.

We notice immediately that the current flows only while there is movement of the magnet, and that no current flows when the magnet is stationary, whether inside or outside the coil. We can express this in another way by saying that current flows when the magnetism through it is *varying*, or, as some textbooks put it, when the magnetic lines of force are varying in number.

If we could continue to push the magnet in and out we could create a current which would be flowing all the time, though reversing in direction—in other words, an alternating current. This is impracticable, but we can get the same effect by rotating a rather flat coil in the magnetic field between the opposite poles of a magnet twisted round to make the poles face each other. This is the principle of the alternator. The work is done by steam or by oil or coal gas combustion. If we wish to make only direct current, we must add a device known as a commutator. The machine is then usually known as a generator.

Electromagnetic Induction.—Let us make up two circuits as shown in Fig. 24. The two spirals

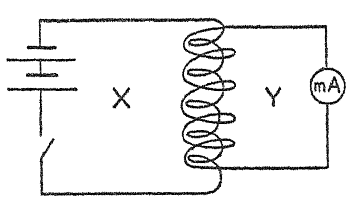

Fig. 24

superimposed indicate that the two coils are near each other and in alignment. They may even be wound on the same insulated cylinder, provided that the wire is

itself insulated so that the turns of one coil do not touch the turns of the other electrically. If we switch on circuit X, there is a kick in the milliammeter of circuit Y. When we switch off circuit X, there is another kick, in the opposite direction. By putting an iron core through the cylinder (if the two coils are on the same one) we can make the effect much bigger.

The explanation of this is that when we close circuit X an electromagnet is suddenly made and so magnetic lines of force suddenly pass through the coil of circuit Y. This change of magnetism causes the current. Switching off makes another change of magnetic flux and current flows again momentarily. In other words, the effect is just as if we had plunged a magnet into the coil of circuit Y and then withdrawn it. If the coils are arranged at right angles the phenomenon is not observable because the magnetic lines of force of one coil do not now pass through (*i.e.*, along the axis of) the second coil. If the two coils are in alignment but further apart the effect is decreased, thus showing that we can strengthen or weaken the effect of one coil on the other by the tightness or looseness of the *coupling*.

Instead of making and breaking the circuit X, we can supply it with a source of alternating current. This is constantly reversing its direction, and the effect on circuit Y is just the same as before but continuous. So we see that we can make an alternating current flow in a circuit by coupling it magnetically to another circuit in which A.C. is flowing. The second current is said to be *induced*. The direction of the induced current is opposite to that of the exciting current. In addition, the induced current itself reacts back on the first coil. The induction is thus seen to be *mutual*.

INDUCTANCE OR SELF-INDUCTION.—We can get a somewhat similar effect by the use of one coil only. Let an alternating current flow through the coil of Fig.

25. Then the first turn p has magnetic flux changing with the A.C. supply. This flux does not stop abruptly but passes into turn q, and turn r and so on. Similarly the current through turn q causes a varying magnetic flux through p, r, s, etc. This changing magnetic flux reacts back on the coil to induce in it an alternating

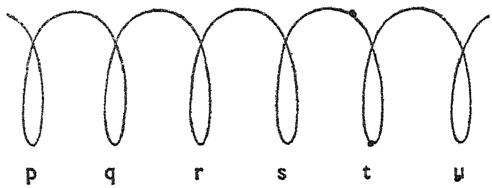

Fig. 25

current. This is *self-induced* and has the effect of opposing the current already made to flow by the outside A.C. supply. This opposing force is called *inductance*, and is measured in henries, millihenries, or microhenries. It is a most important property of any coil for wireless work.

We speak only of a coil. But the effect is observable even in a straight wire though to a much smaller extent. So any wire has some inductance however small. A core of magnetic material (iron or iron alloy) increases the effect in the case of a coil.

As an E.M.F. or a p.d. is essential before a current can flow, it is more usual to speak of induced E.M.F. rather than of induced current.

The sparking of a simple D.C. circuit when it is made or broken quickly is due to inductance. The speed of making or breaking induces an E.M.F. high enough to spark across a small air gap.

CHAPTER III

ALTERNATING CURRENT

THIS sort of current has been mentioned before but we must examine its characteristics a little more closely. The ordinary A.C. if plotted on a graph has the shape of a simple wave. In scientific language it is the same shape as a sine curve, or in other words its shape is sinusoidal.

The sine curve is, as we said in Chapter I, the shape of the graph of y=sinx plotted with x on the horizontal axis and y on the vertical axis. 'Sinx' means 'the sine of x' and is a mathematical function reasonably simple to understand. Let us consider the diagram of Fig. 26. The triangle XYZ has a right angle at Z. If we

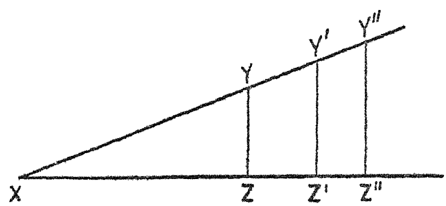

Fig. 26

measure YZ and divide it by XY, we get an answer which is the ratio of YZ to XY. Now if we continue the arms of the angle further and draw Y′Z′ and divide it by XY′, we get again a ratio. We can go on doing this with Y″ Z″, etc., and we find that the ratio is the same all the time. It depends on the angle only. A different angle would have a different value for this ratio. It is called the *sine* of the angle X. The values of the sines

of all angles (down to the nearest minute of angle) between 0 and 360 have been worked out and put into mathematical tables. There are other ratios, such as the *tangent* and the *cosine*, but we are concerned here with the sine only. There is no need to tabulate the values of the sines of angles bigger than 90 degrees (this is a right angle, a quarter of the whole angle at the centre of a circle) because the sine of any angle between 90 and 180 is equal to the sine of the angle left when the original is subtracted from 180. For example, the sine of 150 is the sine of 180—150, *i.e.*, 30. In a somewhat similar way the sines of angles between 180 and 360 can be found by simple manipulation of the angles, as was done for the example in Chapter I. After the angle

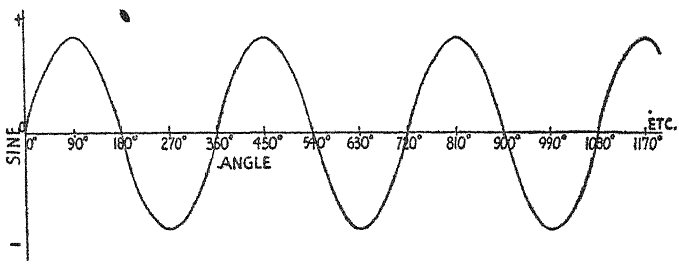

Fig. 27

360 degrees is reached we start all over again. Now if we plot the value of the sine on the vertical axis corresponding to the value of the angle on the horizontal axis, we get a graph which looks like Fig. 27. We recognise it at once as the shape given for a simple wave in Chapter I. In arguments on waves and alternating current of E.M.F. we start from the sinusoidal form as a basis.

The preference for a certain shape may well seem arbitrary. But it is not. Anyone who cares to measure the projections on a diameter of the rotating radius of a circle will find that if he plots length of projection against angle he will get a sine curve. Now A.C. is

made by rotating a coil of wire in a magnetic field, and as it rotates the number of lines of force which can pass through it obviously depends on the projection of the coil. Fig. 28 will help us to understand this. An end-on view of a single loop is shown in three positions in the magnetic field. In (a) the maximum number of lines of force pass through the loop. In (b) only a fraction of the total lines passes through the loop, and the fraction depends on the vertical area available, in other words

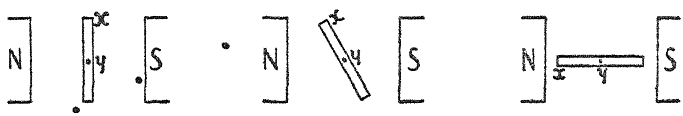

Fig. 28

the projection of the length xy on a vertical line. In (c) no lines at all pass through the loop. So as the loop rotates, the current (which depends on the lines) varies from zero to maximum, then to zero, then to a maximum in the opposite direction, then to zero again, all in one rotation. The current represented on a graph is plainly a sine curve. This is not the only reason for the use of the sine curve, as was explained in Chapter I. So we see that there is a real basis for using the sine curve as the simplest form of A.C. and of a wave.

In the language of mathematics, an alternating current is expressed by the equation.

$$I = I_0 \sin 2\pi ft.$$

where I=value of current at any instant

I_0=maximum value of the current

π('pi')=ratio of circumference of a circle to its diameter

f=frequency of complete alternations

t=time in seconds.

In Chapter I we touched on 'phase'. We can express this more exactly. Let us suppose that there are two

alternating currents a and b, shown in one graph as in Fig. 29. Though they are both A.C. and have the same maximum value yet they are slightly different. The curve b is seen to be displaced by an amount equal to a quarter of a cycle with regard to a. If the equation of a is $I=I_0 \sin 2\pi ft$, then the equation of b would be $I=I_0 \sin (2\pi ft+\alpha)$, where α is the difference in angle to make the sine values of b from those of a. This is called the phase difference, and is exactly 90 degrees

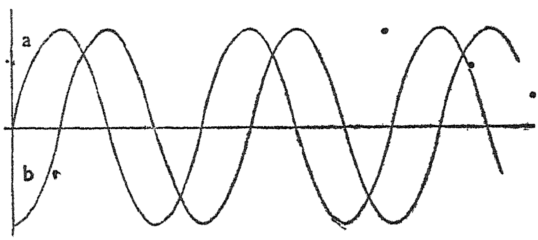

Fig. 29

in the case illustrated. The two currents are said to be 90 degrees out of phase. Another way of measuring angles is by using 2π radians instead of 360 degrees, and with this 'circular measure' as it is called, the angle 90 degrees is represented by $\pi/_2$. Thus we can express the difference between the two as a phase difference of $\pi/_2$ radians. Applying the same argument to two waves superimposed, we see that the complete interference mentioned in Chapter I is due to a phase difference of π radians or 180 degrees. If two waves or alternating currents get their maxima and minima at the same moment, there is no difference of phase at all. $\alpha=O$. They are said to be 'in phase'.

Alternating E.M.F. is made by means of an alternator, as stated above. But it can also be made by means of valve circuits under special conditions, as we shall see later. The valve oscillator, as it is called, is quite a

usual piece of laboratory apparatus. There is no cell or battery of any sort whatever which can produce A.C.

In diagrams a source of alternating E.M.F. is shown by means of one cycle of a sine curve inside a circle, thus :——

Transformers.—We saw previously that an alternating E.M.F. can be induced in a circuit by the magnetic linkage with a primary circuit in which alternating

AIR CORED TRANSFORMER IRON-CORED TRANSFORMER

Fig. 30

current is flowing. This fact is made use of in wireless work. The device which effects the linkage is known as a *transformer* and it is indicated in diagrams by two parallel spirals, these having straight lines between them if the transformer has an iron core. These are shown in Fig. 30.

The actual construction of the transformer is somewhat as follows: If there is no iron core then a coil is wound on a 'former' of insulating material and the second coil is wound either over the first or beside it. If there is an iron core the make-up is more complex. Layers of the core are shaped in such a way that when placed alternately on an increasing pile they make up a laminated structure of the form shown in Fig. 31. This makes up the core and a complete external circuit. The coils are wound on card formers to fit over the centre

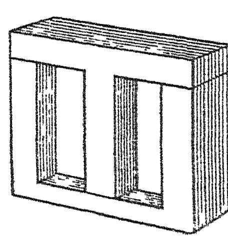

Fig. 31

core and in fact when the transformer is made the laminations are added to the coils instead of being made up in the way we have described, laminations first. The laminations are then bound together in frames and fixed on a base. With small transformers a moulded case is put over the whole thing for the sake of appearance. The ends of each coil are brought out in some way to terminals outside the moulded case. The large transformers (*i.e.*, large for wireless work, but really minute compared with the heavy duty transformers used in the distribution of high voltage supplies about the country) used for taking supplies from the mains are not normally covered but the connections are brought to a terminal strip on top of the structure.

Many coils may be wound on the same transformer. We have considered the simplest case of two coils only but more are often necessary.

The great usefulness of a transformer is not due merely to the induced E.M.F. but rather to the change in size of this E.M.F. For if we have one coil of twenty turns and the other of forty turns, then if the E.M.F. across the first is 10 V. that across the second will be 20 V. or, if the E.M.F. across the 40 turns is 10 V. then the E.M.F. induced across the 20 turns will be 5 V. The *step-up* or *step-down*, as the case may be, is equal to the ratio of turns. This is obviously very convenient. By suitable choice of turns ration we can get 1000 V. from 10 V. or 2 V. from 200 V. (choosing these figures at random).

A mains transformer for wireless work may be required to give 350 V. to the rectifier, 4 V. to the heaters of the valves, and 4 V. to the heater of the rectifier. For certain reasons not to be given here such a transformer may have some coils *centre-tapped* (*i.e.*, with a connection to the electrical centre of the coil). The diagram of the transformer mentioned above

would then be as in Fig. 32. We do not attempt to indicate the number of turns by the number of loops in the spiral.

The convenience of stepping up an E.M.F. must not be misinterpreted. 1000 V. can certainly be had from 10 V. by means of a transformer, but something is not gained for nothing. As soon as another circuit is connected to the higher voltage, current flows and energy is consumed. The rate of expenditure of energy, or, in other words, the *power* of an electrical circuit is measured in *watts* (and milliwatts or kilowatts) which are obtained by multiplying the E.M.F. by the current. And the power of the circuit on the 1000 V. side of the transformer will be equal to the power of the 10 V. side, if the transformer is 100% efficient, which it never is. A few figures will make this point clear. If the 10 V. side has a current flowing of 10 A. then the power consumed is 100 watts. So with a hundred per cent efficient transformer we can get 100 watts from the other coil. If the E.M.F. is 1000 V. then the current is ·1 A. or 100 mA. That is, the resistance of this circuit must be 10000 ohms. If we attempt to use a circuit of less resistance, the current is increased and so the watts are more. If the 10 V. side has a supply which will respond to the increased demand, we can get what we want within limits but only by increasing the power consumption on the 10 V. side. The ability to respond is limited by the size of the wire which will burn out when the current reaches a certain figure depending on the diameter of the wire, and by the resistance of the winding. Also the supply itself will decrease in voltage as extra current is taken, though the mains supply will stand a lot of current before this drop

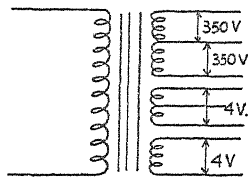

Fig. 32

begins. A battery, however, will stand very little increase. In addition the mutual inductance acts as a stopper to the current, but for simplicity we can keep to the purely resistive circuit. So in practice there is always a limit to what power we can draw from the transformer, and the latter has to be very carefully designed in regard to iron core area, wire diameter, and number of turns in order to be used for any special purpose.

The coil to which we supply the energy is called the *primary*, and the one from which we draw the energy with its altered E.M.F. is called the *secondary*.

The efficiency of any machine, electrical or otherwise, is a very important factor in practice. Never do we get out all the energy put in. In other words the efficiency is never 100%. There are always losses due chiefly to friction in mechanical devices and heating in electrical ones. In addition, with a transformer, the magnetic changes do not respond instantly to the electrical changes, and so there is residual magnetism trying to induce an opposing E.M.F. This is called *hysteresis*, and is a source of loss in a transformer. This effect increases with the frequency of the alternations and with really high frequency current we cannot use a core at all. The *high-frequency* (H.F.) transformer is therefore wound on an insulated former. There is also loss of magnetism due to any gaps in the iron core of an ordinary transformer, just as there is with a bar magnet. This is minimised by making the core a closed circuit. This is the reason for the special shape of the laminations. The latter are used instead of solid iron to minimise the losses due to still another cause—electric currents induced in the core itself. All these losses and the heating loss (for energy is being used up to make heat) bring the efficiency of a 'good' wireless transformer down to about 80%.

When the core has a high permeability there is more magnetic flux and so more linkage and we can reduce the size of the core accordingly. Two special alloys for greater permeability have been used for wireless work. One is an alloy of steel and silicon (4% silicon) and is used for the mains transformers. Another is an alloy of iron and nickel (up to 50% nickel according to manufacturer and purpose) with a much greater permeability. It suffers, however, from the fact that if the flux density is high (*i.e.*, if the ampere-turns are high) then the efficiency rapidly decreases. So the nickel-iron alloy can be used for the cores of small transformers used inside the valve circuits of the wireless set. Some of these may be as small as to measure but an inch or so in linear dimension.

THE INDUCTION COIL.—The step-up principle is used in a piece of apparatus familiar to every schoolboy. In this a primary of a small number of turns has in series in its circuit a make-and-break device similar to that of an electric bell. Thus a sort of alternating current is created though not sinusoidal in form. A secondary of a very large number of turns is wound over the primary and when the primary circuit is switched on, the voltage is high enough across the secondary to produce a spark, some 30000 volts being necessary to produce a spark of about an inch in length. The secondary voltage may not be large enough to make a spark and yet be sufficient to give a 'shock' to anyone who holds the ends of the secondary winding. This is the toy 'shocking' coil.

ROOT-MEAN-SQUARE.—An alternating current is varying in size all the time. It reaches every half-cycle a maximum value, and passes through zero in between. The average effect therefore on an ordinary ammeter needle is zero. So instruments of a special design must be used for A.C. measurements. But something

is happening even if the ammeter shows nothing and we wish to express the result in amperes, or, if E.M.F., in volts. We actually use a figure which indicates the D.C. which would give the same heating effect. This is independent of the direction of the current. If we were to choose the maximum value, or 'peak' value as it is called, to indicate the current we should have a different figure for A.C. and D.C. for the same heating. For example, a current which reaches a maximum of 10 A. every hundredth of a second would not have the same heating effect as a direct current of 10 A. because the former is zero every hundredth of a second, with intermediate values corresponding to the sine curve already illustrated. If we are dealing with E.M.F. and we have an alternating one of peak value 100 V. we should have to keep in use two values of E.M.F. for the same heating effect. The salesman would have to say that an electric fire would operate at its best on 100 V. A.C. or, say, 60 V. D.C. (according to what D.C. value the former is equivalent for heating). So we actually choose the equivalent heating effect value of an alternating current in order to rate it. This is called the *root-mean-square* (R.M.S.) rating. When we speak of an A.C. supply of 230 volts we mean 230 volts R.M.S. This means that the peak value is actually about 325 V. If we square this figure we get 105625. But the voltage is zero at every interval in between equal to the interval at which it is 325 V. So the *mean* of this squared value is 52822·5. If we take the square root of this we get 230 approximately. This is the origin of the expression root-mean-square. The precise argument for the choice of this figure depends on the mathematics of the sine curve.

The alternations of ordinary domestic A.C. supply are so rapid (fifty cycles per second) that a fire or a lamp has no time to cool right down between the peaks.

That is why we can operate a lamp or fire on an A.C. supply just as easily as on a D.C. one.

CONDENSERS.—Two conductors separated by an insulator constitute a condenser. The insulator used is air, mica, bakelite or paraffined paper. It is not always practicable to have merely two plates opposite each other, and so the condenser is often built up by having two long conducting strips separated by paraffined paper or mica and then rolling the strip up, keeping an insulator between successive turns to separate the parts of metal which might touch. Sometimes we achieve an extra area of plate by having two sets of connected parallel plates interleaved. This is indicated in Fig. 33. However it is made, the condenser is shown in dia-

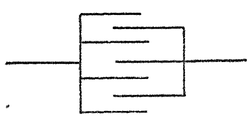

Fig. 33

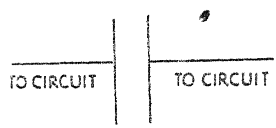

Fig. 34

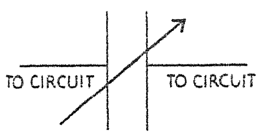

Fig. 35

grams by two parallel straight lines as shown in Fig. 34. If we wish to be able to alter the area of plates facing each other, we must have a mechanism to make the condenser *variable*. This is indicated in diagram as in Fig. 35. The arrow shows variability at the will of the listener or constructor. The invariable one is a 'fixed' condenser.

It is our aim to have condensers of known value in a wireless receiving set. But we must remember that any two conductors separated by insulator constitute a condenser and so every set has a number of such

accidental unwanted condensers in it and the designer has to plan to evade them.

The action of a condenser in a circuit is peculiar. Consider first a D.C. circuit as shown in Fig. 36.

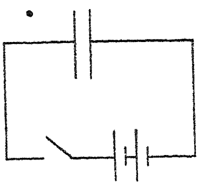

Fig. 36

When the switch is closed the source is in circuit with the condenser. The E.M.F. is as we already know due to a difference of electrons. They are heaped up on one pole and missing from the other. When the switch of this circuit is closed these electrons spread through the conductor from the negative pole to the condenser and from the other side of the condenser to the positive pole of the battery, thus creating on the condenser plates an electrical pressure due to the excess of electrons on one and deficiency on the other. In other words a p.d. exists between the plates. This slight and almost instantaneous movement of electrons is a current, called the charging current, and so if there were an ammeter in the circuit of Fig. 36 the needle would give a quiver on closing the switch but would at once return to zero. After this first kick there is no current and so in this D.C. circuit the condenser is a gap. There is in the ordinary sense no closed circuit.

Now if the switch is opened and the charged condenser is short-circuited with a conductor, there is a spark as the p.d. is suddenly released to make a temporary current. This is the discharging current.

Anyone can perform this experiment with a high-tension battery, a fixed condenser, a screw-driver and a switch. Connect the battery to the switch and condenser. Switch on. Switch off. Hold the metal part of the screwdriver across the terminals of the condenser.

This ability to store up a charge has given the condenser its name.

In an A.C. circuit the action is different in result though due to the same cause. Consider the circuit of Fig. 37. When the switch is closed the charging current flows for the first quarter cycle of the alternating current. Then this current decreases to zero and the condenser discharges. Then the A.C. increases in the opposite direction and charges up the condenser and decreases to zero again and the condenser again discharges. Then the cycle of operations is repeated. So there is a charging current then a discharging current and then a charging current, etc. A milliammeter as shown in the diagram would be the ordinary sort and would respond only if the alternations were very slow and if it were of the centre-zero type. If we have an instrument that will read A.C., however, it will respond at any frequency and give a reading. Thus the condenser does not prevent current flowing in an A.C. circuit. Because of this action it is said to 'pass' A.C. So a condenser is a gap in a D.C. circuit and 'blocks' the current, but has no such effect in an A.C. circuit.

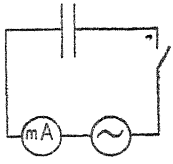

Fig. 37

We have said it has no effect. That is not strictly true for the condenser charging and discharging current is not in phase with the alternating supply. This fact we will come back to later on.

By altering the dimensions of a condenser we alter its electrical properties. We can increase the area of plates, decrease the distance between them, or change from air as separator to a solid insulator. The effect of all or any of these is to increase the charge which must be given to the condenser to raise the p.d. between the plates by one volt. The charge necessary to raise the p.d. by 1 volt is called the *capacity* of the condenser. So the effect of any or all the changes above is to increase the capacity. This is measured in *farads*, microfarads

(μF. or sometimes mfd.), or micromicrofarads ($\mu\mu$F. or sometimes mmfd.). A condenser of capacity 1 farad would be enormous, and the condensers used in wireless work have always capacities measured in μF. or $\mu\mu$F.

We note that the capacity can be increased by enlarging the plates. This is the reason for the method of construction given above. A variable condenser has interleaving plates, one set fixed and the other set on a spindle. As we rotate the spindle we therefore increase or decrease the area interleaving and so increase or decrease the capacity.

Another type of variable condenser has one arched plate which is pressed down towards the second plate (with mica in between) by twisting a screw. This is called the *pre-set* variable condenser.

The type with interleaving plates is used for tuning a wireless set. Whenever we turn the knob we operate such a variable condenser. The mechanism varies. In early sets the rotation was effected directly by means of a dial, and we could see how far the rotation had gone by watching a fixed point on the dial pass a scale of degrees. To-day more elaborate methods are in use. Sometimes a mechanism is added which moves a vertical strip horizontally across an illuminated rectangular orifice on which are printed wavelengths or even the names of broadcasting stations. In some sets a little neon tube is used, the glow of which reaches a maximum when we have rotated the condenser vanes (as they are called) exactly the right amount for reception of a certain station. A still more up-to-date device includes the use of a small electric motor to rotate the vanes, and we press a button to switch on the motor and then the associated mechanism stops the vanes at the right position, according to the button pressed. This is press-button tuning.

The essential point for us to grasp is that we invariably alter the capacity of a variable condenser when we 'tune' a wireless receiver.

The material used between the plates of a condenser is called the *dielectric*, and the figure which determines its effectiveness compared with air is called the *dielectric constant*. So if we use a separator of high dielectric constant we can make the condenser much smaller. But dielectrics have disadvantages. The chief is that they use up energy as heat. This is the same effect as resistance, and so a condenser has always associated with it a resistance value which in all good quality condensers is very high.

There is one type of condenser which has a very high capacity yet is not of tremendous dimensions. It is the electrolytic condenser. It can have a capacity of the order of 1000 μF. in a block no bigger than one of ordinary type of capacity 8 μF. The construction is that a central spiral plate of aluminium has on it a thin film, deposited electrolytically, which has a very high resistance. This makes the dielectric. Chemicals are added to this and the whole surrounded by the second plate of copper. A precaution must be used with this type. It cannot be used in an ordinary A.C. circuit, but can be used for separating D.C. from A.C. and then the aluminium *must* be connected to the *positive* side of the applied voltage, otherwise it is damaged for ever.

When condensers are connected in parallel their capacities can be added together to find the equivalent capacity of the combination. When they are in series they obey the reciprocal equation similar to that used for resistances in parallel. If C is the equivalent capacity of separate condensers of capacities C_1, C_2, etc., in series, then the equation is:

$$\frac{1}{C}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\text{ etc.}$$

The ordinary tuning condensers have maximum capacities of about ·0005 μF. Condensers used in the mains filters have capacities of from 2 to 8 μF. Electrolytic condensers have very high capacities as already stated. Fixed condensers in the receiver have values varying from ·0001 μF. to ·5 μF. Variable tuning condensers for use with ultra-short waves have maximum capacities much smaller, usually measurable in μ μF.

REACTANCE.—We have said that with a coil of wire there is always inductance. The effect of this is to create in an A.C. circuit a back E.M.F. which tends to oppose the one supplying the circuit. This cuts down the current. The back E.M.F. is proportional to the rate of change of the current, and as this rate is greatest when the current sine curve is passing through zero, the back E.M.F. is a maximum then. So the phase difference between back E.M.F. and the current is exactly 90 degrees or $\pi/_2$ radians, the current being behind the E.M.F. or 'lagging'.

The effect of the inductance in cutting down the current is known as the *inductive reactance* and is equal in value to $2\,\pi f L$ where f is the frequency and L is the inductance. This reactance is measured in ohms.

With a condenser in an A.C. circuit, the current and E.M.F. are again out of phase as has been previously stated. Once more the phase difference is 90 degrees or $\pi/_2$ radians, but this time the current is ahead of the E.M.F. or 'leading'.

Again the effect is to oppose and we get *capacitative reactance*, equal in value to $\frac{1}{2\,\pi fC}$, where f is the frequency and C is the capacity.

The reactance of an inductance is seen to increase with the frequency, whereas the reactance of a condenser decreases with the frequency. So the higher the frequency of the applied A.C., the easier the path

provided by a condenser but the more difficult the path provided by an inductance. We see also that the reactance of a condenser decreases as the capacity is increased and the reactance of a coil increases as the inductance is increased. These effects are shown in Table I.

TABLE I

Frequency of A.C. supply cycles per per second.	Reactance of coil having inductance of 200 μH. ohms	Reactance of coil having inductance of 40 H. ohms	Reactance of condenser of capacity .0002μ F. ohms	Reactance of condenser of capacity 2μ F. ohms
50	·06	12000	15950000	1595
15000	18	3600000	53000	5·32
1000000	1200	$7{\cdot}2 \times 10^{10}$	797·5	·0798
10^7 (10 mega-cycles per sec.)	12000	$7{\cdot}2 \times 10^{11}$	79·75	·008

The normal house supply is 50 cycles per second. A condenser of 2 μF. capacity offers a reactance to this of 1595 ohms whereas a choke of 40 henries offers a reactance of 12000 ohms. So we can use a combination of 40 henries and 2 μF. to filter off the 50 cycle A.C. supply from any D.C. present (and they are both present after rectification of the main supply—see Chapter XIV). The condenser by-passes the A.C. and is a block to the D.C. whereas the coil resists the A.C. and passes the D.C. This is the basic idea of a *filter*.

A coil used for its reactance is called a *choke* for obvious reasons. The H.F. choke has no iron core but other chokes have all core of iron alloy.

IMPEDANCE.—Always there is in a circuit some resis-

tance, and so the calculations above cannot always be applied so simply. The combined resistive effect of inductive reactance and resistance, capacitative reactance and resistance, or both reactances and resistance, is called the *impedance*, usually denoted by the letter Z.

With resistance r and inductive reactance $2\pi fL$ in series the impedance equals $\sqrt{r^2+L^2 4\pi^2 f^2}$. The impedance of a capacitative reactance $\frac{1}{2\pi fC}$ and resistance r in series is $\sqrt{r^2+\frac{1}{C^2 4\pi^2 f^2}}$. For resistance and reactance in parallel, calling the reactance X whether it is capacitative or inductive, the impedance is $\frac{Xr}{\sqrt{r^2+X^2}}$. Impedance in an A.C. circuit has the same effect as resistance in a D.C. one. So we get for A.C. circuits an imitation of Ohm's Law, *viz.*

$$E=IZ$$

$$Z=\frac{E}{I}$$

$$I=\frac{E}{Z}$$

where E=R.M.S. value of E.M.F., I=R.M.S. current, Z=impedance. When the impedance is merely a reactance the same relations hold, calling the reactance X and placing it in place of Z in the equations.

INDUCTANCE AND CAPACITY.—When both coil and condenser are in series and there is a resistive effect also due to the ohmic resistance of the wire and the dielectric losses, we get an important result. If the

inductance is L, the capacity is C and the resistance is R (usually called the 'equivalent series resistance' because it is not present as a separate component), the impedance Z is given by

$$Z = \sqrt{R^2 + \left[2\pi fL - \frac{1}{2\pi fC}\right]^2}$$

The circuit for this is given in Fig. 38 where an A.C. supply is provided.

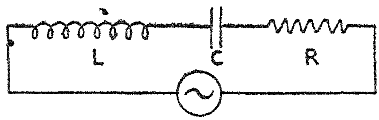

Fig. 38

The current will be at its greatest when the impedance is least, for the current I is E divided by Z. Z is least when

$$2\pi fL = \frac{1}{2\pi fC}$$

for when these are *not* equal the result is squared and so it does not matter which is the bigger the total Z will be increased. Then by simple algebra,

$$2\pi fL = \frac{1}{2\pi fC}$$

$$\therefore\ 4\pi^2 f^2 CL = 1$$

$$\therefore\ f^2 = \frac{1}{4\pi^2 CL}$$

$$\therefore\ f = \frac{1}{2\pi\sqrt{CL}}$$

This arrangement of inductance and capacity in series,

because at a certain frequency the current is a maximum is called an *acceptor* circuit.

If we have the circuit of Fig. 39, the inductance is in parallel with the capacity, and the alternating E.M.F. is applied across both of them. The reactance of L is $2\pi fL$ and the reactance of C is $\frac{1}{2\pi fC}$. Therefore if the applied E.M.F. is E, the current in the inductance L is E divided by $2\pi fL$ and that in the capacity C is E multiplied by $2\pi fC$. These are out of phase, one being 90 degrees ahead of the E.M.F. and the other 90 degrees behind it. The

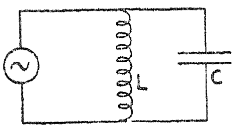

Fig. 39

indifference between the two is therefore 180 degrees of phase, the condition for complete interference. If the current values are equal then this interference causes no current at all to flow in the circuit LC and

$$\frac{E}{2\pi fL} = E2\pi fC$$

$$\therefore \quad f^2 = \frac{1}{4\pi^2 LC}$$

$$\therefore \quad f = \frac{1}{2\pi\sqrt{LC}}$$

This is the same equation as for the series circuit. But in this parallel one, when these conditions occur, the current is a minimum (theoretically zero) and the impedance is a maximum. As the current is a minimum, this circuit is a *rejector*.

But there is never the ideal state of things. Resistance is always present and so the phase difference is not exactly 180 degrees and we do not get the complete nullification of current. At the frequency for this

theoretically zero current, therefore, there is a slight one flowing. So the impedance is, though large, never infinite.

The effective resistance of the rejector (at the supply frequency given by the formula) is called the *dynamic resistance* and if r is the actual resistance in the circuit, this dynamic resistance is $\frac{L}{Cr}$. As, at this correct frequency, the current through the LC circuit is theoretically nothing, we can replace Fig. 39 by the truer one shown in Fig. 40, where R is the dynamic resistance.

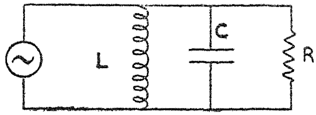

Fig. 40

THE OSCILLATORY CIRCUIT.—If we have a circuit containing inductance L, capacity C, and resistance r, and if we set up somehow in this an electrical disturbance, then if the ratio $\frac{L}{C}$ is greater than r^2, the charge given to the circuit oscillates backwards and forwards, getting gradually weaker, and lasting all the longer if the resistance is very small. The frequency of the oscillation is given by the equation

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{r^2}{4L^2}}$$

If $\frac{r^2}{4L^2}$ is so small that compared with $\frac{1}{LC}$ it is negligible, this equation reduces to

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

which is the same as for maximum current in an acceptor or minimum current in a rejector.

RESONANCE.—In all branches of science where oscillations occur we get the phenomenon of *resonance*. All elastic substances (and most substances are elastic to a certain extent) tend to oscillate if given an initial disturbance. A spiral spring, for example, if stretched and released does not go back immediately to its initial state but instead oscillates up and down. The oscillation decreases in size until the initial state of rest is reached. If a piece of wood is knocked, the surface oscillates long enough to create a few sound waves and we 'hear' the knock. An inductance-capacity circuit has the equivalent oscillatory effect in electrical terms as shown above. All these oscillations are known as 'free' oscillations or vibrations and depend on the characteristics of the substance or circuit. With the spring chosen as an example above the frequency of the oscillations depends on the physical properties of the wire making the spring, and it does not matter how far we stretch it, the frequency of oscillations will always be the same for that particular spring. A wine glass rings when tapped, and the frequency of the note emitted depends on the characteristics of the wine glass. No matter where or how we hit it the note has always the same frequency.

All these free or natural vibrations are those which demand least energy for their creation. Now if we set up a vibration in an object or a circuit in such a way that the vibrations can be conveyed to a second object or circuit, then if the frequency of the vibration happens to be the natural frequency of the second object or circuit, this will start to oscillate. This sympathetic vibration or oscillation can be set up only by a vibration of the correct frequency. This way of setting up vibrations is called *resonance*. The second object or circuit is said to *resonate*. We can illustrate it by finding the note emitted by a tapped wine glass and

then sounding this note on a piano. If the piano is now damped down, the wine glass is heard 'singing'.

With an inductance-capacity circuit the frequency of its natural vibration is given by $f = \frac{1}{2\pi\sqrt{LC}}$. If a frequency of this value is given to the circuit, therefore, there is a maximum response. So the circuit has either maximum current (acceptor) or maximum impedance (rejector) to a frequency given by the above equation. This is another way of saying what has already been said earlier. So the frequency for maximum current in an acceptor or maximum impedance in a rejector is called the 'resonant frequency'. We see that whether we wish a circuit to respond to an applied alternating E.M.F. or to oscillate by giving it energy, the frequency for maximum effect is given by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

MAGNIFICATION.—In an acceptor circuit, the voltage developed at resonance across the inductance is equal to that across the capacity, and they are in opposite phase. So the total power consumed is equal to that consumed in the resistance. Let us imagine the applied E.M.F. is E volts R.M.S. Then if the resistance is r, the current will be E divided by r at resonance. But the reactance of the inductance L is $2\pi fL$ and so the E.M.F. developed at resonance across the inductance is $2\pi fL \times \frac{E}{r}$. The ratio of this to the applied E.M.F. is therefore $\frac{2\pi fL}{r}$. This can be quite large. For example, if $L = 200\ \mu\,\Omega$, $r = 10\ \Omega$ and $E = 10$ mV. or $10000\ \mu$V., and $C = \cdot 0003\ \mu$F., then the resonant

frequency $$f=\frac{1}{2\,\pi\sqrt{LC}}$$

$$=\frac{1}{2\,\pi\sqrt{200\times\cdot0003}}$$

$$=\frac{1}{2\,\pi\sqrt{\cdot06}}$$

=approximately 650 kilocycles per sec.

The reactance of L is $2\,\pi fL$

$=2\times3\cdot1416\times650000\times200\times10^{-6}$ ohms.

$=2\times3\cdot1416\times6\cdot5\times10^{5}\times2\times10^{-4}$ ohms.

$=2\times3\cdot1416\times6\cdot5\times2\times10$ ohms.

=approximately 817 ohms.

The voltage developed across this

$$=817\times\frac{10\text{mV.}}{10\text{ ohms}}$$

$$=\frac{817\times10\times10^{-2}}{10}\text{ volts}$$

$=\cdot817$ volts or 817 millivolts.

This is 81·7 times as big as the applied E.M.F.

The ratio is in fact $\frac{2\,\pi fL}{r}=\frac{817}{10}=81\cdot7$. This is called the *magnification* of the circuit. Owing to the E.M.F. across L being opposite in phase to the E.M.F. across C, there is power consumed only in the resistance. But nevertheless we can utilise one of the two E.M.F.'s so developed.

A rejector circuit, consisting of a capacity, and an inductance and a resistance in a closed series circuit has the same properties once an oscillation is set up in it. Again the magnification is $\frac{2\,\pi fL}{r}$ across the inductance.

We have spoken of the resistance quite freely. In

Chapter II it was stated that this resistance depended on the diameter of the wire, its length, and its material. But with alternating current of high frequency this is no longer true, and the higher the frequency the greater is the resistance. In the arguments on acceptor and rejector circuits, therefore, when we are considering high-frequency alternations we must use the H.F. resistance of the circuit for r. This consists of the H.F. resistance of the wire itself, the H.F. resistance of contacts (such as valve pins in their holders) and the stray H.F. resistance of condenser connections, and dielectric losses.

CHAPTER IV

WIRELESS WAVES

FARADAY was the most eminent of all physicists first to suggest that if an electric charge is moved, energy travels out into space in the form of a wave. He guessed happily that the speed of such a wave might be that of light. His notion was that every unit of electric charge had attached to it a tube of force disappearing into infinite space, and if the unit of charge were moved then a kink would travel along that tube until the whole of it had taken up the new position.

Clerk-Maxwell, another physicist, who was also a mathematician (which Faraday was not) many years later showed theoretically that the early guess was right. A movement of an electric charge would cause a wave to travel with the speed of light and that speed would be independent of the charge and its connections. The movement of the charge was the 'splash' in the ether analogous to the stone's fall in the placid pond considered in Chapter I. For a continuous stream of waves the charge had to be moved backwards and forwards. Expressed in another way, an alternating current had to be made to flow and then a wave would be associated with it.

All this, though interesting to theorists and exciting to some physicists, had no very great importance in the history of wireless transmission until the German Jew, Heinrich Hertz, a physicist, experimented in 1886 and onwards at Bonn. On the continent even to-day

frequency is expressed in 'hertz' instead of cycles per second, in honour of this man.

Hertz utilised the discharge of a condenser across an air gap to make his electrical disturbance. He had two spheres a foot in diameter to act as a condenser and connected each to a rod ending in a small knob. The two knobs were adjusted near each other until when the spheres were charged from an induction coil a spark passed across the gap. But the spark was not just one single discharge in one direction; it passed backwards and forwards across the gap many times. There were in Hertz's experiment some 33 discharges in one millionth of a second. The discharge was, in other words, oscillatory and of high frequency.

To detect any waves that might be emitted into space (Hertz was experimenting, not having any factual evidence of the existence of such waves) he bent some seven feet of wire into a circle with the ends not quite touching. On these ends he fixed small balls. He kept on adjusting the air gap and altering the capacity of the condenser so formed by soldering on pieces of metal to the balls. At last he succeeded in getting a response at a distance of twenty metres (nearly twenty-two yards). When the discharge passed across the first air gap, a spark was produced in the gap of his balled loop. This was just over fifty years ago.

Hertz then went on to prove that the radiated electrical disturbance was in wave form. He did this by reflecting the transmitted energy from a metal plate back towards his oscillator. When continuous waves are reflected, the incident wave is meeting the reflected one and interference occurs. The result is that there are equidistant points of the space between emitter and reflector at which there is no motion at all and other equidistant points at which there is maximum motion.

In the case of electrical waves, there are points of no current and points of maximum current, all the points being fixed. Such waves are called 'standing' or 'stationary' waves. Hertz utilised his knowledge of such waves for sound and tried to find them for his electrical disturbances. He succeeded. He then found their wavelength which was twice the distance between successive points of no current. He knew the frequency of his oscillator by the characteristics of the circuit. Then he applied the equation $v = f\lambda$ and proved that the speed of the waves was that of light, 300000000 centimetres per second, or approximately 186000 miles per second.

This remarkable work showed practically that Maxwell and Faraday had been right. An electrical disturbance would travel with the speed of light as a wave through all space. Both Faraday and Maxwell were dead before Hertz demonstrated the truth of the one's guess and the other's mathematical analysis. Excitement spread among the scientists of the world and soon hundreds were at work examining the new transmission of waves in the ether.

Along with the electrical variations of the wave were associated magnetic variations. A moving electron creates magnetism as was explained in Chapter III if the speed varies. So we find that the wave demonstrated by Hertz was an *electromagnetic* wave. The magnetic force in such a wave is at right angles to the electric force.

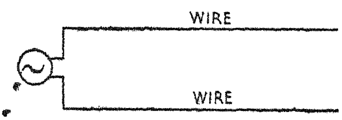

Fig. 41

At the time of Hertz's experiments, Sir (then Dr.) Oliver Lodge was experimenting in England on a different electrical problem, though it was associated with the German scientist's work. Lodge proved that electricity could oscillate along a wire. If we have

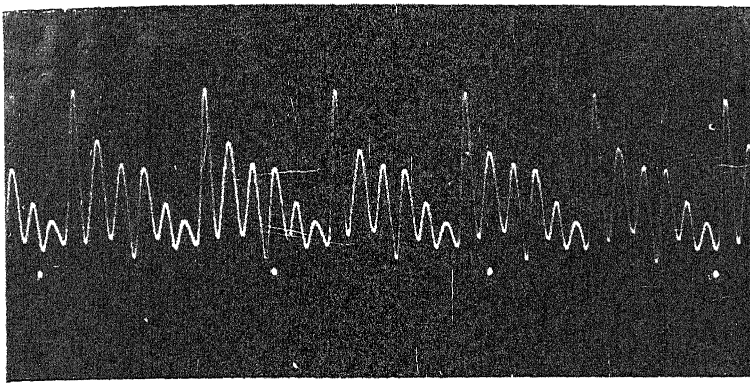

FIG. 1.

The sound curve of the vowel ā in father, intoned by a bass voice at pitch F. The dots below the curve indicate intervals of 1/100 second

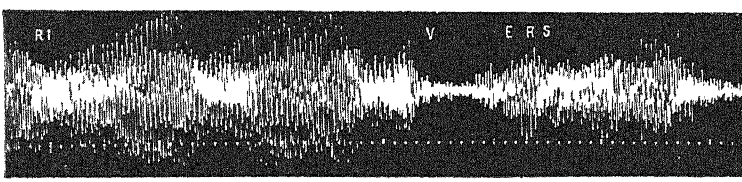

FIG. 2.

The sound-curve of a gramophone record of a baritone voice singing the word rivers to the accompaniment of an orchestra. The dots below the curve again indicate intervals of 1/100 second, so that the curve is much more compressed than that shown in fig. 1

TYPICAL SOUND-CURVES

By courtesy of Dayton C. Miller

Plate I

a circuit as in Fig. 41 we can move a tube containing gas at low pressure along the wires, bridging them, and at the points corresponding to maximum potential difference the tube glows. The distance between successive positions of maximum glow brightness is half the wavelength. This arrangement is that of 'Lecher' wires after a scientist working on the problem at the same time as Lodge. It is used even to-day for measuring wavelengths of the order of a few centimetres.

THE EARTH.—The next fact that emerged was that there were always associated with the waves in the wires, waves in the space outside, and that the speed of both sets of waves was that of light. This gave rise to the use of the earth in the experiments, because the thoughts of all the workers were concentrated on *communication* by means of the waves known to travel so freely in space.

The earth is an electrical conductor of a poor sort. Let us consider a circuit arranged as in Fig. 42. If waves are generated in such a wire, they run up the wire, are reflected 180 degrees out of phase and run down again. As they enter the earth the energy spreads out round the foot of the wire in circles like the ripples round our stone in Chapter I. Associated with the earth wave is the equivalent free wave from the open end of the wire, and so the waves spread over the surface of the earth half in and half out of it. If the surface is made more a conductor at the foot of the wire by means of copper strips and network, the waves travel further.

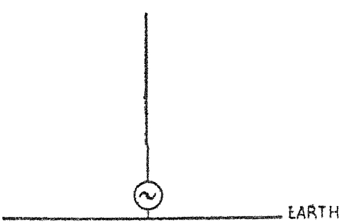

Fig. 42

The vertical wire is in fact an *aerial* or *antenna.*

It can be shown mathematically that the natural wavelength of the vertical aerial is four times the length of the wire. This fact is utilised to-day in the design of aerials for the reception of the waves used in television, and for the aerials used in beam transmission across the world. For an unearthed Hertzian oscillator the corresponding relationship is that the natural wavelength of the oscillator is twice the length of both parts combined. The earthed aerial acts also

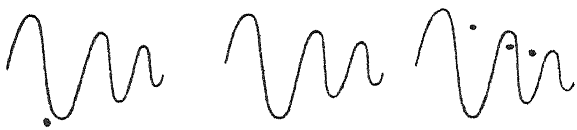

Fig. 43

just as if it were the upper half of two wires in alignment with a spark gap at the earth's surface, in other words just like Hertz's oscillator.

The tremendous practical advantage of the earthed system, as distinct from an insulated Hertzian oscillator, is that all the apparatus of the circuit can be near the earth and not right up in the air.

The sea is a better conductor than the ground, and so communication by the earthed system over intervening sea is easier than over intervening ground. The earliest practical communication was made over the sea for this reason.

Wireless Telegraphy.—It was soon realised that a spark emitted a series of dying waves, 'damped' waves as they are called, something like those indicated diagrammatically in Fig. 43. Each train represents one spark which is of course really a rapid series of sparks. Now if there is a switch in the primary circuit of an induction coil, these waves can be made to continue for as long as the switch is closed. The type of switch used

was called a 'key' and the operator would depress it for as long as he wished. Morse of America invented a code of short and long strokes, whether of sound, of flag, of sun flashes, or of electricity, by means of which the letters of the alphabet could be transmitted. Calling a short stroke a dot and a long one a dash, the letter S is represented by 'dot dot dot' and the letter O by 'dash dash dash'. The simplicity of sending and receiving the signal S O S can be readily appreciated.

With the use of the morse code and a key, the sparks could then be translated into letters of the alphabet. All that was necessary was to be able to detect these dots and dashes when they arrived. Numbers of inventions were thought out—the magnetic detector, Lodge's coherer, and eventually the crystal contact detector called the 'perikon'. The resistance of this detector would decrease when excited by an incoming wave and the current would increase and this effect could be made to show on a tape. Or instead, the resulting long and short strokes would give long and short musical notes in a telephone. In H.M. Navy such perikon and telephone receivers were still in use as recently as 1918.

Sir Oliver Lodge, in 1894, at Oxford, sent messages across a few hundred yards of space by utilising a tape recorder. His oscillator and his receiver were on the Hertzian model. This was the earliest recorded successful transmission of a message over any real distance without communicating wires. It was the first 'wireless' transmission and reception.

Immediately workers in many countries were interested and the names of inventors excited scientific people—Jackson, Popoff, Marconi. The latter came from Italy in 1896 to demonstrate the improvements he had made in Lodge's apparatus.

The excitation of an aerial by a spark was soon the

accepted most convenient way of creating the electromagnetic waves. But this method had disadvantages. The first was that the 'tuning' of the receiving station necessitated an aerial of the same dimensions as that of the transmitter, for best results. And even then signals on all sorts of wavelengths could still be received. In a word, the receiver was not *selective*, and a mixture of signals was received.

The solution of this problem takes us back to Chapter III. Every straight wire has inductance, but a coil has it to a very much greater extent. If we load an aerial with a coil, therefore, most of the inductance is in the coil. This was done by Lodge and the selectivity of transmitter and receiver very much increased because any aerial could be utilised with the correct amount of inductance coil, and because the aerial was an inductance-capacity circuit, the inductance of which could be varied by making a sliding contact on the coil.

The next stage brought us to the modern principle of tuning, for a condenser was added to the circuit. Now the maximum effect is produced by an inductance-capacity circuit at a frequency given by the equation $f=\frac{1}{2\pi\sqrt{LC}}$ (see Chapter III), and so this could be adjusted to be the same both at transmitter and receiver. In fact, by tuning we could get resonance.

Marconi gave a great impetus to the progress when he made a commercial company in 1897. This enabled him to have large sums of money for research, much more than was available to the private experimenter or university professor. Thenceforward the name of Marconi became associated in the minds of most people with the word 'wireless'.

The other great disadvantage of the spark telegraphy was that as each spark was a heavily damped train of waves, much time was wasted between sparks and

energy was dissipated as the waves died. So some other means of excitation was sought for to produce 'continuous' waves. There were several systems, and in each the waves had to be interrupted in order to produce for a dot or a dash a sequence of spurts to give a musical note in the receiver telephone. All the methods were revolutionised by the invention and improvement of the *valve*, to be considered in a later chapter.

Finally, we may say that the Marconi company experimented with transatlantic communication between England and America and at last, after years of disappointments, opened a service in 1907 between a station at Clifden on the west coast of Ireland and one at Glace Bay in Nova Scotia. The first dramatic use of the new method of communication came with the arrest of Mr. Crippen, wanted for murder, as he was on a liner going to America.

WIRELESS TELEPHONY.—Several years elapsed after wireless telegraphy by spark or interrupted continuous wave was in regular use before any success came to those who imagined that speech could be transmitted in a similar way.

Speech and music are heard by means of waves in the air, usually very complicated waves. These waves can produce corresponding electrical variations in a circuit by the use of a microphone. In the ordinary telephone mouthpiece this microphone consists of carbon granules behind a diaphragm. When the latter is made to move by air waves the packing of the granules is affected in response. Carbon granules have less electrical resistance when compressed, and in proportion to the compression, than when loose. So if they form part of a circuit containing a battery, the current normally flowing will increase or decrease with the movement of the granules. So a single pure note

(*i.e.*, one producing an air wave which when drawn in diagram is a sine curve) of fifty cycles per second will produce an electrical variation of fifty cycles per second. For broadcasting to-day carbon microphones are not used, but instead less sensitive but more accurate ones. However, the theoretical basis of an electrical response to an air wave is the same for all types.

These electrical variations can be made to affect a single continuous wave manufactured in another circuit. The result of the change made in the wave is that its magnitude varies in accordance with the electrical variations due to the speech and music.

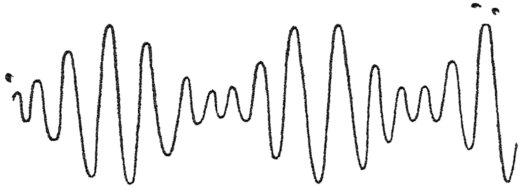

Fig. 44

This wave is said to be *modulated.* Some idea of what is happening can be gained by a look at Fig. 44. The wave is shown and the alteration of its magnitude with a single pure note of sine-curve form. The relative frequencies cannot be shown in a diagram. The wave being modulated is called the *carrier*, and may have a frequency of, say, one million cycles per second. A note of fifty cycles per second used to modulate such a carrier would contain ten thousand of the latter waves within one 'bulge'. That is why we cannot draw a diagram in the correct proportions.

If the strength of the added variations reaches a maximum which reduces the carrier to nothing, the modulation is said to be 100%. The fraction indicating the degree of modulation is found by dividing the height above the axis of the curve for the unmodulated carrier into the difference in height between the

maximum of the modulated carrier and the value for the carrier. This is multiplied by 100 to bring it to a percentage. Put into figures, this means that if the peak value of the voltage of a carrier is 2 volts, then if the modulation makes it increase to 3 volts (and decrease to 1 volt of course), the modulation depth is $\frac{3-2}{2} \times 100 = 50\%$.

In practice, the 'envelope' of the modulated carrier is rarely a sine curve. It is much more irregular due to the complexity of the electrical variations due to speech and music.

SIDEBANDS.—An unmodulated carrier occupies no 'space' in the ether. If it has a frequency of 1000 kc/s (kilocycles per second) then it has that frequency only. But when it is modulated this is no longer true, for the addition of the electrical variations due to sound makes the frequency rather different. Mathematical analysis is the only sure way to grasp this, and we can put the fact simply without proving it. If, say, a carrier of 1000 kc/s is modulated by an electrical variation of 1 kc/s, then the resultant wave can be shown mathematically to be just the same as if we were to plot three waves, of 1001 kc/s, 1000 kc/s, and 999 kc/s, and add them up. In other words, the frequency now extends over a band of 2 kc/s. It is called the *sideband width.*

With speech and music, as before stated, the applied modulation has not one single frequency. It varies from about 20 cycles per second up to about 20,000 cycles per second, if all the possible audible frequencies are used. So the sidebands contain all these frequencies, and the maximum width is 40,000 cycles per second or 40 kc/s. This means that a station transmitting on 1000 kc/s would occupy a 'space' in the ether from 980 kc/s to 1020 kc/s. A wave of frequency

1000 kc/s has a wavelength of 300 metres, and the wavelengths corresponding to 980 kc/s and 1020 kc/s are 306 metres and (about) 294 metres, respectively. So if another station were to broadcast on, say, 290 metres (about 1034 kc/s), with a sideband width of 40 kc/s, one of its sidebands would interfere with the sideband of the 1000 kc/s signal. So therefore there should be no station broadcasting on wavelengths between 288·5 metres and 312·5 metres, if there is to be no interference whatever. Hence, approximately, there could be only about ten broadcasting stations using the band of wavelengths from 250 to 500 metres. This, in view of every nation's needs and every company's demands, has been found to be impracticable, and a compromise has been arrived at whereby stations are separated by a width of 9 kc/s. Thus there can be a station broadcasting on 991 kc/s, another on 1000 kc/s, and another on 1009 kc/s, by international agreement. This reduction of permissible band width means that the highest frequency of speech or music which can be used without risk of interfering with others is 4500 cycles per second, very short of 20000 cycles per second. This introduces a special problem as we shall see later. Things in the world of broadcasting are not quite so bad as they seem, however, because the two stations nearest to the one taken as example at a frequency of 1000 kc/s may be so far away geographically that a receiver does not get any interference even if the band width of the 1000 kc/s wave is extended to, say, 20 kc/s. We can quote the present state of affairs as an example. London National transmits on 1149 kc/s, and the station next to it in frequency is a small-powered one in Czechoslovakia (1158 kc/s). The station nearest in frequency the other way (1140 kc/s) is a low-powered one in Italy. In fact the two stations using high power nearest to 1149 kc/s are Stagshaw

(1122 kc/s) and Nice (1185 kc/s), so the London National transmissions can have all the band width they need without causing any interference to listeners in Great Britain. The type of interference mentioned above wherein the sidebands overlap gives rise to a peculiar sort of background noise called graphically *sideband splash.*

The cutting out of the higher audible frequencies in order to stop interference causes *distortion.* We shall consider this more in dealing with receivers and with loudspeakers and gramophones.

The Travel of Wireless Waves.—When an aerial is excited and waves travel out into space, they travel along the earth as has been said, bending with the earth's curvature. Also waves go out into the atmosphere, and we talk of the *ground ray* and the *sky ray* to indicate the line of travel of the earth-attracted waves and of those spreading into the atmosphere, thus treating them all as straight lines.

Most ordinary reception is due to the ground ray. As this ray progresses it loses part of its energy, and at the same time it gets weaker owing to the spread as it gets further away. It loses part of its energy to every electrical conductor it encounters, whether aerial or metal structure, and it loses part of its energy in resistance losses in the ground. All this loss is called *attenuation.*

There is considerable difference between waves, according to their length, with regard to attenuation. The longer the wavelength, the less is the attenuation and so reception is possible at greater distances as the wavelength is increased. The shorter the wavelength, the greater is the attenuation.

The nature of the intervening ground makes a difference, and experiments have shown that attenuation is more rapid over rocky ground than over soft earth.

The least attenuation (independent of wavelength difference) is over water.

The attenuation due to electrically-conducting obstacles makes it possible for a receiver to be 'screened' from a transmitter by intervening metal structures. In a large city this is quite noticeable.

The sky ray is attenuated but little, though other things happen to it as we shall see later. At very short wavelengths (*i.e.*, at very high frequencies) the attenuation due to the atmosphere is however noticeable. Those below 5 centimetres (about 2 inches) in wavelength travel only a few yards due to the attenuation by absorption by water and carbon dioxide.

WAVELENGTHS IN USE.—Marconi found that long waves travelled further, there being less attenuation of the ground ray. We might think therefore that all broadcasting could advantageously be done on the long waves. But the high power necessary for long distances and the 'crowding of the ether' have prevented that. A little arithmetic will illustrate the point. Let us broadcast on, say, a wavelength of 1500 metres (200 kc/s). Then if we occupy a band width of 9 kc/s, the nearest broadcasting stations in frequency will be 191 kc/s and 209 kc/s, corresponding to wavelengths of (approximately) 1571 metres and (approximately) 1435 metres, a total 'spread', unoccupied, of 136 metres. So in the range of wavelengths between 1000 metres and 2000 metres there would be space for but about seventeen stations if they were near and powerful enough to interfere.

The waves from about 800 metres in length to about 2000 metres are known as *long* for convenience of discussion. The band below this between 200 metres and 600 metres is called the *medium-waveband.* Waves between 600 metres and 800 metres are in use for ships and post-office telegraphy and for very little broad-

casting of telephony. On the medium waves the position with regard to crowding is rather better and over a hundred stations can be accommodated, because 9 kc/s is but 1% of 900 kc/s (wavelength of 333 metres) whereas it is 5% of 180 kc/s (wavelength of 1667 metres) as used on the long-waveband. Anyone who cares to do some arithmetic can verify these facts.

Below 100 metres we get to what are known as the *short* waves. Let us consider a signal with a carrier frequency of 6000 kc/s (wavelength of 50 metres). Then 9 kc/s is but ·15% of this, and so more than 2000 stations can be accommodated between 12 metres and 60 metres.

The above accommodation is arrived at by dividing the range of frequencies by the minimum of 9 kc/s for each station. Actually many stations are of low power and well separated by geographical distance and so do not interfere. This increases the possible number of stations on every waveband.

For these reasons we can see that each nation has but a few stations on the long waves and rather more on the medium waves. Why, then, do we not use the short waves? We do, but not for ordinary broadcasting because the range of the ground ray is so small. The sky ray, however, will travel long distances, as will be more fully explained below. So we find the short waves used by amateurs (who have been successively turned off each band) and by stations broadcasting over long distances such as the transmitters for the British Empire.

It should be clear by now that it is more convenient for us to think and calculate in terms of frequency rather than of wavelength, for a certain frequency difference means the same thing on all frequencies, whereas a wavelength difference means different things according to the waveband being discussed. Thus on the long-waveband, a wavelength difference of 20

ground ray and sky ray or if we are far enough away to get only the sky ray, in which case we cannot receive the signal at all during the day. When the ground ray and sky ray are about equal in intensity we get the worst fading. On the long waves we receive the ground ray much more strongly than the sky ray and so fading is not nearly as noticeable.

We talk of 'reflection'. Actually the process is one of gradual bending and not the sudden reversal more correctly termed reflection. However, as the result is a return to the earth we may use the word 'reflection' to cover both phenomena for our purposes.

Ionisation is a process of electrification of a gas by extracting electrons. It is caused in the atmosphere by the ultraviolet rays from the sun and decreases in intensity as the sun sets. The ionisation causes not only reflection but also absorption and the latter is all the greater with more intense ionisation. So after sunset there is less absorption and the refracted rays pass in and out of the layers and return to earth. That is why we notice the effect so much more at night.

With the short waves the effects of the ionosphere are dramatic. Over thousands of miles by night we can hear the signals from stations of quite low power. A little arithmetic will show that reflection at a greater height means a greater corresponding distance over the earth's surface.

The ground ray of a short wave is rapidly attenuated and so is not received at more than, say, 90 miles from the broadcasting station, the actual distance depending on the wavelength and the power. But at night that same wave, by sky ray, may be received over the thousands of miles already mentioned. As this sky ray is reflected, it is possible for a receiver to be under the curve of the reflection and so not receive the signal. The distance in which no signal is receivable is called

the *skip distance*. The sky rays are not all at one angle, of course, and so when they reach the earth after reflection, they cover a certain area instead of being only in one spot. Fig. 45 illustrates this, though the reflection is shown as if being sharp like that reflected from a plane mirror. But actually this reflection is a process of gradual refraction. There is a certain maximum angle that the sky ray must make with the

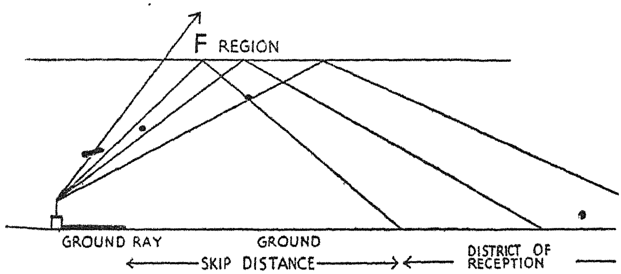

Fig. 45

ground, and any ray at an angle greater than this goes through the ionospheric region to upset the Martians if the wave survives so far. The diagram illustrates this also. There is no skip distance for waves longer than about 75 metres, and long waves are reflected even if going vertically upwards. Waves less than about 10 metres in length are not reflected by either the E or F layers.

Owing to the vagaries of the ionospheric activities, short-wave reception is not reliable unless very well controlled at the transmitter. Our own reception from America or elsewhere for rebroadcasting has often suffered, as many listeners can recall. The broadcasting to the British Empire is very carefully thought out, and so the wavelength used and the aerials used vary according to the time of the day and the season of the year and the district to be served in order to make reception as reliable as humanly possible. Over a long distance, some of it is in darkness while the rest is lit

by the sun, and this affects the reflection of the short waves. The areas in light and darkness are changing with the rotation of the earth. It is to meet these changes that different wavelengths are used from hour to hour.

This discussion of the effect of the ionosphere cannot be left without a mention of 'atmospherics'. These are disturbances due to electrical discharges and they cause crackles and hisses in the receiving set. They are more noticeable on the long waves.

POWER.—The range of a broadcasting station is in proportion to the electrical power dissipated in the aerial. This is estimated in kilowatts. Stations radiating on small power can be accommodated in many countries on the same wavelength without causing interference with each other's signal. So there are more broadcasting stations than seemed possible when we discussed the 9 kc/s separation. A table of a few broadcasting stations with their wavelengths, frequencies and power is given in Table II.

TABLE II

Station	Wavelengths in metres	Frequency in kc/s	Power in kilowatts
Radio Paris ..	1648	182	80
Deutschlandsender	1571	191	60
Droitwich	1500	200	150
Moscow	1744	172	500
London Regional ..	342·1	877	70
London National ..	261·1	1149	20
Radio-Normandie ..	274	1095	20
Pittsburg	48·83	6140	28
	25·26	11870	24
	19·72	15210	18
	13·93	21540	6

We may mention before leaving the subject of wireless waves, that the wavelength used by Hertz was of the order of a few metres . . . ultra-short waves. Those used by Lodge in his experiments soon afterwards had waves a few centimetres long . . . micro-waves. Marconi in his transatlantic telegraphy used wavelengths up to 20000 metres. Hertz also found that a parabolic reflector would concentrate the waves into a beam, just as with light. This type of reflector has been used for the micro-wave experiments, and the beam notion is used for the short wave broadcasts to the British Empire, though the reflector is no longer a metal paraboloid.

CHAPTER V

CHOOSING THE SIGNAL

THE sequence of events before we can hear the entertainment at the broadcasting station can now readily be appreciated.

1. A performer (or performers) utters sounds by mouth or instrument in front of a microphone.
2. These sounds are transmuted to electrical variations.
3. These electrical variations are made to modulate a high-frequency carrier wave.
4. This modulated carrier excites an earthed aerial system.
5. The broadcast carrier travels through space close to the ground and up into the air.
6. The carrier meets a conductor and excites in it variations of electric current over the same band of frequencies as the modulated carrier.
7. These currents in the conductor are somehow chosen from amongst all the currents excited by several passing waves.
8. The chosen currents are divested of the carrier and so emerge as electrical variations corresponding to those made by the microphone at the broadcasting station.
9. These electrical variations are changed back into air waves and we hear.

To these steps may be added either: 7a. Magnification of the high-frequency currents before we abstract the carrier, or 8a. Magnification of the currents after the carrier is abstracted, or both of these. 7a would come

between step 7 and step 8, and 8a would come between step 8 and step 9.

We have grasped an outline of steps 1 to 5, and we can now consider steps 6 and 7 and part of 8.

Picking up the Signal.—An aerial and earth system is used to produce a current response to the passing wave.

The aerial is a conductor projecting into the air. For simple theory it should be a straight vertical wire, and for ordinary broadcast reception its length is small compared with the wavelength. For example, we may be receiving a signal on 342 metres (London Regional) which is about 1120 feet, but our aerial must not be more than 100 feet long including down lead, by the authority of the Postmaster General. This restriction has the double effect of preventing unsightly and dangerous high amateur structures and of stopping the possibility of powerful illegal transmission. Even if we listen on a wavelength of 60 metres, or 186·5 feet, our aerial is still smaller than the wavelength.

Any conductor will suffice as an aerial though insulated copper is the commonest. An iron bedstead, a metal curtain rod, a wire clothes line—all have been used quite successfully.

To-day, owing to valves, our sets are so sensitive that the exact design of aerial is not very important. But if we bring it near to earthed structures we must remember that we are adding a capacitative effect and in result the aerial becomes very inefficient. One thing is certain and that is that the unsightly swaying and drunken masts festooned with rope and wire, or rooftop cages and other weird shapes are entirely unnecessary. If we cannot have a high conductor free of nearby structures, we can make do with almost any indoor substitute.

If the aerial is outdoors we must have some means of

reception on the ultra-short waves will be considered under these headings. Some all-mains receivers have a socket for 'mains' aerial, which means that the electric wiring of the building is used as an aerial. It is clear from what has already been said that this sort must be very inefficient.

A *frame* aerial is a large coil, usually on a square or rectangular frame. One end of the winding is connected to the aerial terminal of the set and the other end to the earth terminal. The ordinary aerial picks up some of the electrical energy in the incoming waves, but the frame aerial although it does this to a very limited extent is affected more by the magnetic waves which cause, owing to the changes of linkage with the alternations, currents in the winding. The maximum effect is obtained when the frame is directed with its edges in line with the direction of the wanted wave. The minimum effect is obtained when the open face of the frame faces this direction. This directional effect of a frame aerial can assist the selectivity of the set.

The voltage developed across the frame aerial owing to the induced current in it is very small and so the frame aerial is suitable only if we have a very sensitive receiver. As an example of the sort of winding required we may note that a frame of 3-inch wood made as a square of 18 inches side and wound with 14 turns of wire would suffice for medium-wave reception.

It is obvious that if the ground ray is the one being received, as it usually is, then we shall find an advantage in connecting our set to earth. We do this by making as good a contact as we can to the ground nearby. If this ground is damp the earth so damped is a better conductor, for moisture increases the conductivity of any absorptive material. The actual connection can be made by copper tube, metal bucket, or any metal of

large surface. The joint to the wire to be led to the receiver must be made so that it cannot be corroded by weathering or by electrolytic action due to the presence of chemicals in the soil. A common practice is to use a water pipe for the earth connection. For those awkwardly situated in flats this is a good method. Gas pipes make an earth connection also, though less efficiently than water pipes. The danger often talked about that explosion may result is negligible. Should lightning strike it would get the gas pipes whether or not the wireless set were connected to them.

We can often manage without an earth, but efficiency is gained by the use of a good earth connection. We have but to consider the original Hertzian oscillator to realise that two conductors will radiate when situated near each other and both excited by high-frequency currents. We can receive in like manner and instead of using an earth we can put up a wire like an aerial but underneath it and separated from it. This is sometimes called a *counterpoise* aerial. It is connected to the earth terminal of the set. Aeroplanes are provided with wireless receivers and transmitters and so earth connections are clearly not used in such cases.

An outside earth wire is usually brought to a lead-in tube of the sort used for the aerial. An indoor earth wire from a pipe is brought inconspicuously to the set round corners and along the floor, neatly tacked down all along. The experimenter is the only one who dispenses with the fripperies of such disguise. *His* earth wire will be all over the place.

It is an advantage for both aerial and earth to have low resistance. This means low high-frequency resistance, and so the conductors used for aerial and earth are usually of copper, stranded, and insulated.

TUNING.—We have examined in Chapter III the conditions for maximum response of a circuit to an

applied E.M.F. The conditions are that the inductance L and capacity C of the circuit must satisfy the equation

$$f=\frac{1}{2\pi\sqrt{LC}}$$

where f is the frequency of the incoming E.M.F. The circuit, as previously explained, is said to be in resonance with the applied E.M.F.

This is the basis of our *tuning* to choose which signal we wish. The aerial and earth are connected to a coil which has its own inductance value. The aerial-earth

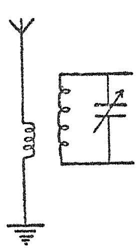

Fig. 46

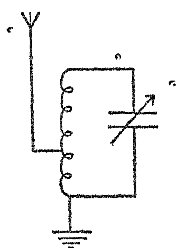

Fig. 47

circuit will therefore resonate to one signal, but in practice it is so far from resonance at any broadcast frequency that it is usually considered untuned or *aperiodic*. The inductance coil of the aerial-earth circuit can be connected to the inductance-capacity circuit in several ways. Before we consider this, however, we must arrange for this second circuit, the real tuning circuit, to be variable, or else it would be permanently tuned to but one frequency. In the old days this variability was affected by a sliding contact on the inductance coil, but to-day it is always done by making the capacity variable. In other words we use a variable condenser. One circuit for the picking up and choice of a signal is given in Fig. 46. Another is shown in Fig. 47. This is called 'auto-transformer' coupling, and the small part of the tuning coil makes part of the aerial-

earth circuit. In the circuit of Fig. 46 the two coils make a high-frequency transformer and the secondary should have about four times the number of turns as the primary for the best practical compromise. This primary is of course in the aerial-earth circuit and the secondary is the actual tuning coil. The lower end of the secondary is usually connected to the earthed end of the primary. With a frame aerial this takes the place of aerial, earth, and primary and secondary, and the tuning condenser is joined across the frame.

We cannot use just any value we like for the inductance and capacity of the tuning circuit. They must satisfy the equation so often quoted

$$f=\frac{1}{2\pi\sqrt{LC}}$$

and C must be variable to such an extent that the minimum frequency and maximum frequency of resonance shall cover a certain band of signals, say, the medium-waveband. By a little rearrangement of the above equation and the use of the fundamental wave equation

$$v=f\lambda$$

we can obtain an equation which gives the relationship between resonant wavelength, inductance and capacity.

$$v=f\lambda$$

$$\text{therefore} \quad f=\frac{v}{\lambda}$$

$$\text{and} \quad \lambda=\frac{v}{f}$$

$$\text{Applying} \quad f=\frac{1}{2\pi\sqrt{LC}}$$

we have therefore $\lambda=v\times 2\pi\sqrt{LC}$

where L is in henries, C in farads, λ in centimetres,

excellent charts which enable us to design a coil of any dimensions for any inductance and get the best coil. It is a fact that if the coil is made wide and of wire of low H.F. resistance such as Litz wire (stranded fine wire), then it is 'good'. An iron core would help us to make the coil smaller for the same inductance, but would introduce losses due to eddy currents. If we powder the iron and embed it in an adhesive substance, we can decrease this loss, and so to-day many manufacturers utilise cores of powdered iron in order to save space. And space-saving is important for a mass-produced article in which every item is priced carefully.

As an example of dimensions, we may mention that a coil of 200 μH. inductance can be made by winding 50 turns of wire of such diameter that the windings take up about an inch on a cylindrical former of diameter $2\frac{1}{2}$ inches.

If the variable condenser has semi-circular vanes rotated about the centre of the flat edge (*i.e.*, the centre of the full circle) we notice a peculiar thing. As we rotate we get equal areas of plate interleaved for equal angles of rotation. But the capacity of a condenser is in direct proportion to the area interleaved. So we see that the capacity of such a condenser is in direct proportion to the angle of rotation. But the wavelength of resonance is in proportion to the *square root* of the capacity, so the wavelength to which we tune is in direct proportion to the square root of the angle through which we turn. Let us assume that a rotation of 10 degrees brings us to a wavelength of 200 metres, then a rotation of 40 degrees will bring us to 400 metres, and a rotation of 160 degrees to a wavelength of 800 metres, and as we increase the rotation the number of metres per degree is decreasing. It would be more satisfactory if we could arrange the rotation to be in direct proportion to the wavelength, or, better still, to the

frequency. This need has led to the use of the special shape of variable condenser vanes—a shape with a point at one end and a curve at the other.

SENSITIVITY.—We desire our aerial-earth circuit and the accompanying tuning circuit to be as sensitive as possible in order to pick up and use any minute signal we wish to choose. If the aerial is sufficiently aperiodic it will respond equally well to any signal in proportion to the strength of that signal. But although that seems very desirable we soon realise that this leads to a mixture of signals getting through the tuning circuit, which is never perfect because there is always resistance present which makes the circuit formula of resonance not quite true. So besides the sensitivity there is another quality we find necessary. We wish to choose just the one programme we want and no other. This quality in a receiver is called the *selectivity*.

SELECTIVITY.—Let us plot a graph on which the upright axis respresents the voltage across the coil of a tuning circuit and the horizontal axis represents the frequency of the applied signal. Let us suppose that the frequency of resonance is 1000 kc/s, and that the circuit is tuned to that frequency. Then the resulting curve will be somewhat as shown in Fig. 48. We see from this that although the effect is a maximum at the resonant frequency yet there is still some effect when we are detuned. This means that an incoming signal at 991 kc/s (the nearest one) still causes some response in the tuned circuit and so we hear this interfering programme in the background. In other words the circuit has poor *selectivity*. Now if the curve were more

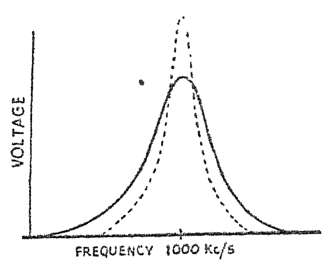

Fig. 48

curve is very much as we have said, but less energy is transferred. If the coupling is 'tightened' we get a curve which has broadened out at the top, and when the coupling is too 'tight' we get an actual drop in the peak of the curve so that there are two peaks with a hollow in between. Other things being equal, the sort of curve we really need is suggested in Fig. 49, the

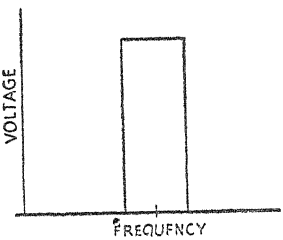

Fig. 49

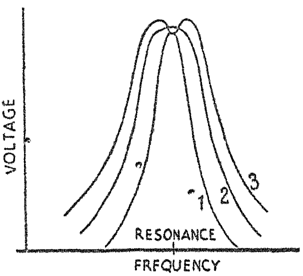

Fig. 50

width of the top being 9 kc/s in order to avoid any interference from the sidebands of the nearest station in frequency. The coupled circuits produce something like this, and as the whole band of frequencies is passed, the whole arrangement is known as a *band-pass filter*. In Fig. 50 are shown three curves for a band-pass filter, No. 1 being for loose coupling, No. 2 for tighter coupling, and No. 3 for such tight coupling as to produce a drop at the top. Though this third curve would seem to be disadvantageous yet in practice it may be all right because the high-note response just 4 kc/s or so off resonance is increased, and as the rest of the receiver often cuts off high-note response, the peaks of No. 3 effect a compensation. Actually the two circuits of a filter are difficult to match perfectly and the curve resulting from too tight a coupling has one peak much higher than the other. The set designer therefore usually prefers to work to a filter whose curve is more like No. 2.

The method of coupling used is also an important point to the set designer, because each has its disadvantages. One method will produce a flat-topped resonance curve, the width of which varies with the

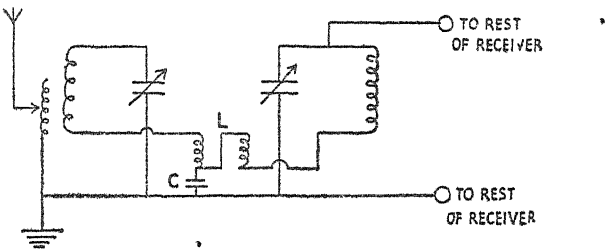

Fig. 51

frequency. A capacity-coupled filter has a top which widens as the frequency of resonance decreases. An inductance-coupled filter widens its response with increase of frequency. So the very best design, ignoring difficulties of costing and mass production, would be mixed coupling. In Fig. 51 is shown a band-pass filter of this sort together with aerial and earth connections. The two variable condensers are ganged together, the coupling being effected by means of the inductance L and the capacity C, both common to both tuning circuits. This circuit was originally given in the *Wireless World.*

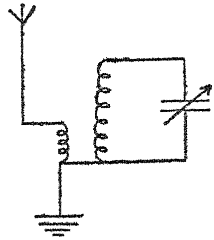

Fig. 52

Any one band-pass filter consists of two tuned circuits and so selectivity can be improved by using yet another complete filter.

Detection.—Let us suppose that we have the circuit of Fig. 52. The aerial is coupled to the tuning coil. Ignoring for the moment the matter of band-pass tuning, we see that we have a device for picking up the signal and a device for tuning to resonance to get a

maximum effect for this one signal. Now if we were to break the tuning circuit and insert a telephone receiver we should not hear the signal. The latter is a modulated carrier of high frequency and has voltage values which rise above and fall below zero many times every second. The result on the comparatively slow-moving telephone diaphragm would therefore be exactly nothing.

In order to get a response to the modulation, which is what we want, the carrier being of no interest to us as entertainment, we must alter it so that the audio-frequency changes can affect the telephone receiver.

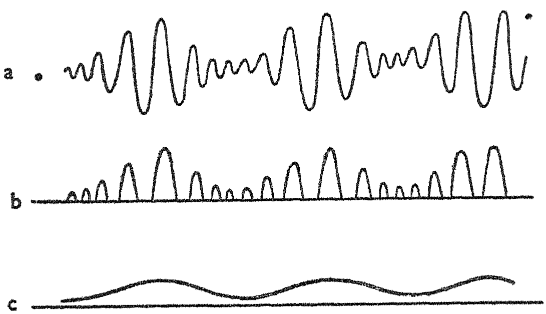

Fig. 53

This process, which *must* happen in every receiver is called *detection* in England and *demodulation* in America.

The circuit of Fig. 53 represents in (a) the modulated carrier. Now if we can cut off one half, the lower one for example, so that the result is as shown in (b), then the average effect in the telephone receiver will be as shown in (c), and the diaphragm will respond to changes at the same rate as, and similar in nature to, the modulation. This is what we must do. The cutting-out of half an A.C. variation is called *rectification*, and when applied to a modulated carrier it is what we actually call detection.

There are several devices for effecting it. The cheapest and simplest is the crystal detector. This consists of a fine point of metal in gentle contact with a crystal of (usually) hertzite. An older variety was the perikon detector mentioned in Chapter IV. This detector is placed in the circuit in series with the telephones as shown in Fig. 54. The voltage developed

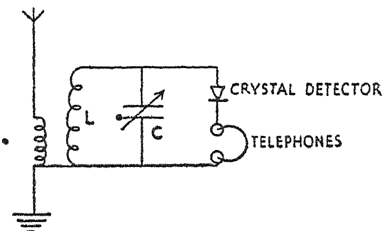

Fig. 54

by tuning across the rejector LC is applied to the detector and telephones. The metal-crystal contact responds more easily to current in one direction than it does to current in the opposite direction. Consequently one half of the current corresponding to the modulated carrier is almost cut out, and the average effect on the telephones responds to the modulation.

Such an arrangement is, therefore, a complete receiver, and as such has given pleasure to thousands of not very skilled amateurs.

If the receiving station is in a remote place where interference is not serious and if the aerial is so inefficient as to make for insensitiveness then the resonance curve, being fairly flat and having sides which slope away gradually, will give good quality reception on a strong incoming signal. That is why one hears occasional moans from the old diehards for the 'good old days'. But a commercial receiver has to be made to satisfy the demand for reception from stations all over the world, and has to be operated in the midst of a

large city or in the remote hills, and in addition there are hundreds more broadcasting stations than there were when broadcasting first began. These facts make the complexity of modern sets so necessary.

It is usual to put a fixed condenser in shunt with the telephones to act as an easier path for the currents still remaining of carrier frequency.

The crystal detector is very unstable. It will go 'off' on receiving a slight shock. It is therefore not good for a commercial receiver. We must have a more reliable detector and we get that in the valve.

CHAPTER VI

THE VALVE

THE THERMIONIC EFFECT.—When a conductor is heated the molecules are agitated. When a certain temperature is reached electrons actually leave their atoms and fly off. This is called *thermionic emission.* Now electrons in motion constitute an electric current, but there is something stopping the thermionic electrons from getting far enough away to bridge any ordinary gap and so make a current. That something is the positive charge on the heated conductor, caused by loss of electrons as explained in Chapter II. This positive charge attracts the negative electrons back to the conductor. In addition any electron which has got far enough away to be beyond the attractive influence of the positive charge exerts a repelling effect on any electron approaching it from the conductor. Consequently a number of electrons returns to the conductor and the rest are concentrated round it, making what is usually called a space-charge.

An ordinary conductor will exhibit this effect but a high temperature is needed, so tungsten was originally used and was made nearly white hot. The coating of this conductor with oxides of the rare earths increases the thermionic emission and so to-day the high temperature is not necessary. Electricity is used to heat the conductor by making this part of a circuit connected to a source of small E.M.F. If this is alternating, it is an advantage for us to surround the conductor with a separate cylinder of material which has a high ther-

mionic emission. The emitting cylinder is then said to be *indirectly heated*, whereas the ordinary conductor used by itself is *directly heated*, both of them by the passage of electric current through the conductor.

If we heat up a wire in the air, it burns away, so to utilise thermionic emission we must enclose the wire in a vacuum.

THE DIODE.—Now if we put a metal plate opposite the conductor emitting the electrons and if we make this plate very positive by connecting it to the positive pole of a high-tension battery and by connecting the negative pole of this battery to the conductor, then the positive plate will exert a pulling force on the electrons of the space charge.

This is the principle of a device known as a *diode*. It has a *filament* if directly heated, a *heater* surrounded by a *cathode* if indirectly heated, and an *anode* or *plate*, both in a vacuum in a glass container. If the filament is directly heated then it is the electron emitter and is

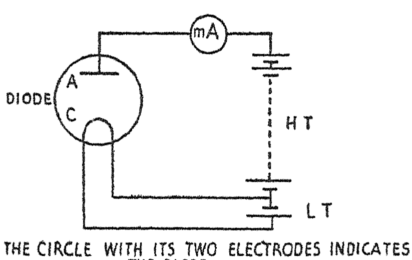

Fig. 55

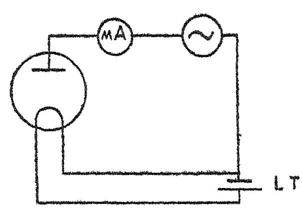

Fig. 56

therefore itself the cathode. The anode and cathode are included in the general term *electrodes* meaning the inside ends of the connections to the outside of the glass container for joining to the circuit. For the observation of this effect we should need the circuit of Fig. 55. With such a circuit the low-tension (L.T.) battery heats up the filament. At the same time the

anode is made positive with respect to the filament by means of the H.T. battery. So electrons go from C to A and current is registered in the milliammeter.

The inventor of this device was Sir Ambrose Fleming. It was the first wireless 'valve'. The significance of the latter name can be easily appreciated. Let us have the circuit of Fig. 56, which is the circuit of Fig. 55 with an A.C. supply instead of a H.T. battery. For one half-cycle the anode is positive with respect to the filament or cathode and electrons flow and a current is registered. For the next half-cycle, however, the anode is negative with respect to the cathode (because the supply is alternating) and so no electrons are attracted and there is no response in the milliammeter. Consequently every half-cycle in which the anode is negative is cut out whereas the other half-cycles cause a current. The average effect of these half-cycles will make a

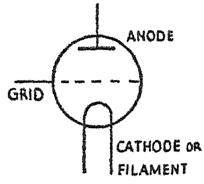

Fig. 57

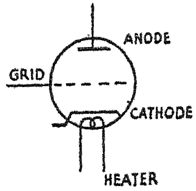

Fig. 58

steady direct current registered in the milliammeter. So we see that the diode has rectified our alternating supply—turned A.C. into D.C. This 'valve' action in allowing current to pass in one direction only accounts for the name so common in Great Britain.

The diode until recently had very little use in wireless sets because an improvement brought about another valve of much more utility.

THE TRIODE.—Dr. Lee de Forest, working in America, found that he could alter the diode very

much by introducing between the anode and the cathode a mesh of wire as an extra electrode. With three electrodes the new valve was a *triode*. The additional electrode is the *grid*. It is shown diagrammatically in Fig. 57, when the cathode is directly heated. Though a circle is used here, the shape varies according to the whim of the draughtsman, sometimes being more like an ellipse, sometimes a rectangle with the corners rounded off. Fig. 58 shows the diagram for an indirectly-heated triode.

Neither of these shows the actual appearance of the triode. The filament is a V-shaped wire in a directly-heated valve and in an indirectly-heated one the heater is hidden inside a narrow cylinder which is the cathode. In each case this electrode is vertical. Around it and a little distance from it is a flattened spiral of wire—the grid. It is supported on stiff wires. Around this and still further away is a plate. Sometimes this plate is flat and does not actually surround the grid, but it is nevertheless in position to receive the electron stream. All these electrodes are rigidly supported inside a glass envelope. The wire connections to the electrodes are brought out through the glass at the bottom and this glass is fused on these wires. A piece of glass tube leads from the inside of the glass envelope to the outside. Through this the air is pumped out and then the glass tube is melted and so the electrodes are left inside the vacuum. This vacuum is not good enough after the action of pumping so a small piece of metal is volatilised inside the glass by heating and absorbs any traces of air and is deposited on the inside of the glass, making it opaque and mirror-like in appearance. The wire connections are brought to a base which has legs on it. These legs will fit into a valveholder which has sockets corresponding to the legs. Thus in a receiver we can remove a valve without breaking every one of its

connections in such a way that they would need repair in order to put in another valve.

On a directly-heated triode there are four pins in the base arranged as shown in Fig. 59. The names of the electrodes connected to these pins are shown. This was

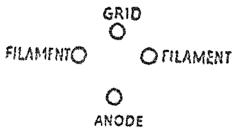

Fig 59

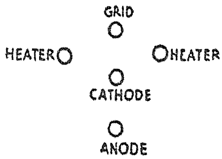

Fig. 60

for many years the standard English valve base. For an indirectly-heated triode there are five pins, the centre one being the cathode connection as shown in Fig. 60.

The effect of the grid is twofold. In the diode, despite the high positive potential on the anode, the space charge is not completely eradicated because of the mutual repulsion of electrons. The addition of a grid in the intervening space, much nearer the cathode, means that it will have a much more immediate effect on the electrons and so help dispel the space charge. The other effect of the grid is that it makes the valve into an amplifier. For example, if the grid is ·1 inch away from the cathode, and the anode is ·5 inch away from the cathode, then a charge of 1 volt on the grid will have as much effect as 5 volts on the anode. The grid is made in mesh because, although the wires trap some of the electrons, the spaces between the wires allow the rest of the electrons to pass through.

There was once a time when one could order a valve as 'detector', 'low-frequency amplifier', and so on according to its purpose, but to-day the available data on any one valve, and the number of types, combine to make the valve descriptions too diverse to be very use-

ful. We must try to grasp a few fundamental principles and learn the rest by experience.

The directly-heated valve of to-day is always for use with a 2-volt supply, unless specifically used for mains rectification or amplifier of large output for public address outfits. The volts on the anode vary from 100 up to 150 for the ordinary 2-volts triode.

The most satisfactory way of studying the behaviour of a valve is by means of graphs. Before we can plot these we must experiment to get the facts for plotting. We can vary the volts put on the grid and read the current in the anode circuit and plot these results on a grid volts—anode current graph. There will be a

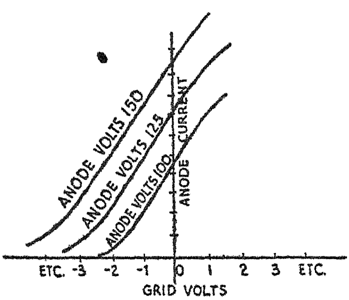

Fig. 61

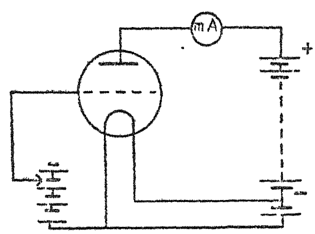

Fig. 62

different curve for each value of anode volts and so we get a 'family' of curves, such as is shown in Fig. 61. The circuit for the test is shown in Fig. 62. We set the anode at 100 volts by plugging into the correct H.T. socket. Then we plug the grid connection, *via* a wander plug, into the socket for 1·5 volts *negative* with respect to the filament and read the milliamps. Then we change the grid plug to 3·0 volts negative and again read the milliamps. So we go on until the anode current is negligible. Then we 'short' from grid to filament and get the current corresponding to zero grid volts. Then we make the grid 1·5 volts *positive* with regard to the filament. The diagram shows the con-

nections for making the grid negative, and so for the latter part of the experiment we must reverse the grid-bias battery. For each value of *plus* grid volts we then get the corresponding anode current. Then we plot all the results. Then we alter the anode volts to, say, 125, and repeat the whole experiment and plot again. Thus we get the family of *characteristic* curves for the valve under test.

From these curves we can derive certain facts which are the constants of the valve. Let us consider Fig. 63 which is a repetition of Fig. 61 with actual scales

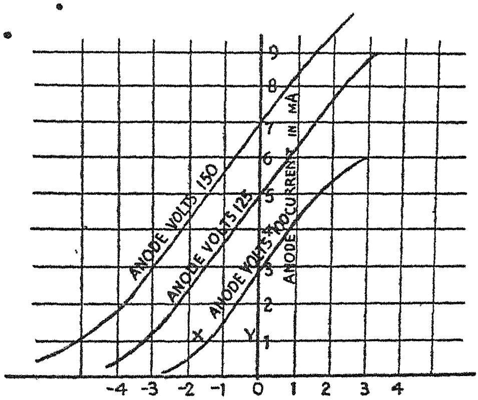

Fig. 63

marked for imaginary curves. At once we see that an increase of 25 volts on the anode produces a change of 2 mA. in the anode current, whatever the grid voltage may be. Let us see what change in grid volts is necessary to produce also a change of 2 mA. in anode current. If we see where the lower curve cuts the upright axis, *viz*, at 3 mA. and trace down through 2 mA. to the 1 mA. level and then trace along from X to Y we see that this distance XY is 1·5 volts. So 1·5 volts change in grid potential will produce a change of 2 mA. in the anode current. Thus we see that the anode volts

change for 2 mA. is 16·7 (25 divided by 1·5) times as much as the change in grid volts necessary to make the same current increase or decrease. This ratio is called the *amplification factor*, and is denoted by the Greek letter μ (pronounced 'mu'). Now let us see what change in milliamps. is produced by one volt change on the grid. Well we already have said that 1·5 volts produce 2 mA. change. So the *mutual conductance* of the valve is 2 divided by 1·5, which comes to 1·33 mA. per volt. We can denote this by g. The 'impedance' or, preferably, the *A.C. resistance*, R_0, can be found from the valve equation $\mu = gR_0$

Then $$R_0 = \frac{\mu}{g}$$

So in this Example $R_0 = 16{\cdot}7$ divided by 2, but if R_0 is to be in ohms, then g must be in amperes per volt. 2 mA. $=$ ·002 A.

So $$R^0 \text{ in ohms} = \frac{16{\cdot}7}{{\cdot}002}$$

$$= \frac{16700}{2} = 8350\ \Omega$$

These are the three constants of the valve and are always given for a triode in valve manufacturers' catalogues. There are other facts given also. For more complicated valves other facts may be more important than the three given, depending on the purposes of such valves, and so these three are not all given.

Another family of curves can be obtained by giving the grid a certain value and finding the resulting current from anode volts changes, and then altering the grid voltage value and repeating the experiment and so on. We then get the anode volts—anode current characteristics, as suggested in Fig. 64. The utility of this family of curves will appear later.

A short study of these families of curves shows us several things. First we notice in the grid volts—anode current curves that each one has a certain length which is a straight line. We notice in the same diagram that the straight portion is longer if we increase the anode volts. We see also that there is curvature at both top and bottom ends of the straight portions. An examination of the anode volts—anode current characteristics shows that there is very little really straight portion. This means that the anode current is hardly *directly proportional* to the anode volts, for direct proportionality always gives a straight line. Also the curves are not parallel or at equal distances apart for equal differences of grid volts.

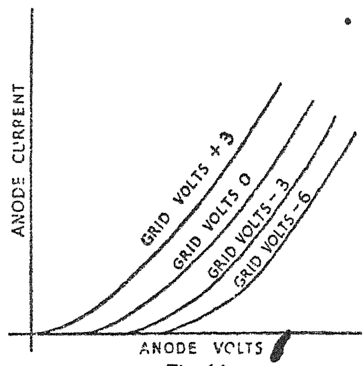

Fig. 64

If we think about these facts we can draw conclusions. When we have a valve in use there is always a *load* of some kind, whether a pure resistance or a coil having impedance, in the anode circuit. Any anode current flowing through this load will produce a voltage across it of value equal to IZ for a coil or IR for a resistance, where I=current, Z=impedance, R=resistance. The bigger the current therefore, the bigger the voltage across the load. This has to be subtracted from the supply voltage (from the H.T. battery) to get the voltage actually on the anode of the valve. So increase of current, if a load is present, produces a certain decrease of anode voltage. Consequently, when we have a load in the anode circuit of a valve, this does not perform as well as the characteristics seem to indicate.

The straight portions of the grid volts—anode current curves become smaller and their slope less. So for working conditions we need not the *static* but the *dynamic* characteristic.

A diagram will help us to understand this point. Fig. 65 shows the circuit of a triode, indicating that any voltage to be utilised is across the grid and cathode whereas the voltage resulting from the amplifying power is used from the ends of the anode load. When

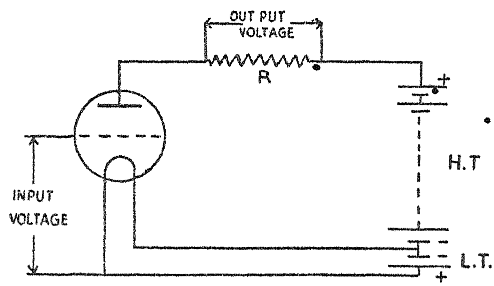

Fig. 65

the electron steam bridges the gap between cathode (or filament) and anode, then direct current flows independent of whether any voltage is applied to the grid—cathode circuit of the valve. Thus if R=10000 ohms and the H.T. battery gives 120 V. and if the direct current is 2 mA. then the drop across R=10000 Ω× ·002 A.=20 V. So the voltage on the anode is really 120 V.—20 V.=100 V.

When the valve is in use, there is an applied alternating E.M.F. and the current in the anode circuit fluctuates accordingly above and below the direct value. A milliammeter will show only the steady D.C. value. We are assuming, of course, that the valve is being used so that the grid volts do not fluctuate to such values as to make the valve work on either of the bends in the grid volts—anode current characteristic. The use of the bend will be considered later. As long as the